Learning Science in Out-of-School Settings

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LEARNING SCIENCE IN OUT-OF-SCHOOL SETTINGS

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Editorial: Learning science in out-of-school settings

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Editorial on the Research Topic
Learning science in out-of-school settings

Introduction

Science learning outside of school or university extends beyond traditional science content and curriculum and contributes to life-long learning. Most people's learning takes place outside of school (Falk and Dierking, 2010) and can be self-directed or facilitated. Transformative and satisfying experiences can be provided through out-of-school science education (Bell et al., 2009) and life-long learning (Rennie et al., 2019).

This Research Topic collected papers about science learning in diverse programs. The articles share insights about program delivery. They document who benefits from those programs, what benefits accrue and how those benefits are assessed.

The Koru Model (Figure 1) provides a framework for lifelong learning and is used to provide an overview of this Research Topic. The Topic includes 19 articles that involve a range of communication avenues, discuss support for learning in out-of-school settings, and address learners' perceived control and impact of learning opportunities on learners' science identities. Innovative evaluation tools are described that provide evidence of outcomes, including longer term impact in some studies.

Communication avenues

Science learning involves information shared *via* diverse avenues. The root system in the Koru Model is the visualization of a vast and interrelated life-long learning ecosystem whereby facts are curated into information and shared *via* various communication avenues. Diversity of learning venues is reflected in the articles in this Research Topic, with the largest number (nine) being centered in cultural institutions (galleries, libraries, museums, science centers), three in natural places, and single reports related to various spaces (community halls, media, playgroups, etc.).

Different venues provide different benefits. Authenticity of science in real-world venues like workplaces (Berg et al.) can increase learner engagement. Individual learners are likely to prefer different communication avenues. Using alternative venues such as cafés (Nesseth et al.) or libraries (Durall et al.; Peterman et al.) can broaden participation by being inviting to those who aren't necessarily already interested in a specific topic or who don't identify with museums or science centers.

Different types of activity also provide different benefits. Science-art residencies (Lau et al.) brought different disciplines together in a shared space to provide opportunities for creativity and intellectual enquiry. In that study, participating scientists reported new ways of thinking about their research while artists learned new theories and processes which they incorporated into their work. In Lykke et al., the use of imaginary worlds in the form of children's plays served as an intuitive understandable guide to an exhibition's interactive features; the importance of balance and bodily coordination also was clearly mediated through fictional activity.

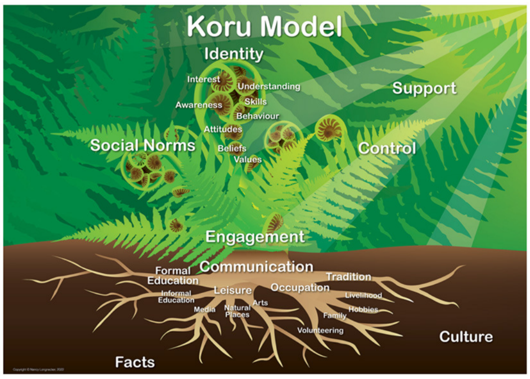

FIGURE 1
The Koru Model of science communication [adapted from Longnecker (2016)]. Individual learners (symbolized by a koru or unfurling fern frond) obtain information from a wide range of communication avenues (roots in this visual metaphor). Learners are more likely to engage with information when it is relevant to them and aligns with their self-perceived identity. Whether and how learners make use of new knowledge is impacted by external factors, including perceived social norms, support, and control. Individual learners use new information to confirm existing schema or to construct new knowledge. The koru is a New Zealand Māori symbol for growth and new beginnings and is used as a sign of respect for mātauranga Māori/ Māori knowledge, culture and values.

Identity

Individual learners may or may not choose to engage with new information and incorporate it into their schema of knowledge. Learners are more likely to engage with new information when it is relevant to their personal needs and interests. Cisneros et al. outline design principles that aligned teen-adult teams based on prior interests and understanding, thereby increasing relevance and likelihood of engagement. Seebacher et al. examine the complexity of learning ecologies and stress the need to adapt to diverse needs and preferences to improve equity of access. Durall et al. address diversity in their *Design for Everyone* principle. Their recommendations include being culturally responsive, showing diversity amongst people engaging in science, fostering diversity in participants, and being sensitive to diverse needs of participants.

Identity is complex, comprising one's values, beliefs, attitudes, awareness, interests, understanding, skills and behavior. As learning is continuous and individual learners construct their knowledge, Falk and Meier recommend that informal educators expand their efforts beyond the temporal and physical boundaries of their programs. Design principles can be used to inspire and motivate (Durall et al.) and to give participants a voice (Howitt and Rennie). The photobook tool used by Howitt and Rennie enabled children as young as three to develop their science identity.

The importance of parents' perceptions of their children as young scientists and attitudes about science was noted in the studies by Howitt and Rennie and Falk and Meier. Cisneros et al. described a multigenerational community conservation program that provides a platform for teens and adults to view themselves as capable contributors to meaningful STEM endeavors. Increased self-concept in science and intention for future participation in science resulted after an intensive week-long experience where young volunteer presenters helped others with interactive exhibits and explained science concepts at a traveling science center (Sripaoraya et al.).

Support

Support is an external factor that influences learners' engagement with and use of information. Support for self-authoring of STEM identities is noted in various articles (e.g., Cisneros et al.; Durall et al.). Massarani et al. described conversations among family groups whose motivations for visiting a museum included leisure, enjoyment and teaching something to a child in the group. In that study, discussions involved caregivers providing explanations to children about specific science concepts like how tides are formed or how the moon moves. Support offered within groups of visitors to the physically interactive exhibition studied by Lykke et al. was more likely to focus on *how* to complete the activities.

Corral et al. demonstrated that facilitators at a science center enabled visitors to use exhibits properly and to engage in advanced learning behaviors. Similarly, the facilitation of rangers who led walks in a national park was impactful for visitors (Forist et al.). Peterman et al. describe a virtual coaching program for out-of-school-time educators, using design-based implementation research to scale up informal education programs in diverse settings.

Control

Design for increased control by learners can impact their use of information. Interactivity is one design feature that provides opportunity for participants to have some control of their experience. For example, Lykke et al. describe interactive features of a whole-body exhibition that enable visitors to interact and transform their experience and new information into new knowledge. They found that group work and planning were engaging features in a whole-body museum exhibition that were important, enhanced interaction and were enjoyed. The features were demanding enough to reduce time for in-depth exploration of the science themes presented. Using learning flow diagrams to illustrate changes in pre- and post-visit responses to physics content questions, Solis et al. demonstrated that visitors who interacted with exhibits were more likely to change to a correct answer, in comparison to non-interacting visitors.

Science Cafés (Nesseth et al.) are designed to be relatively informal and to provide for dialogue between potential learners and experts, giving participants more control over the interaction. Two-way dialogue between experts and users of their knowledge is often a preferable form of science communication when compared to didactic, one-way communication (e.g., Manyweathers et al., 2020).

Another design feature that can enhance participant control is hands-on work with an authentic activity; this may enable participants to develop a sense of ownership of their personal contribution. For example, motivation is enhanced when participants are active contributors to scientific knowledge (Carson et al.) or conservation actions (Cisneros et al.). Berg et al. recommend incorporation of problem-based learning to stimulate learner-centered approaches.

Evaluation tools

Some of the methods reported in this Research Topic involve creative approaches to evaluation of program outcomes. Richard et al. combined concept maps and use of an emoji scale with other data collection methods. Innovative methods included photobooks (Howitt and Rennie), walking interviews (Lykke et al.), and point-of-view camera recording of family museum visits (Massarani et al.). The Zines described by Brown et al. are a flexible tool for reflective evaluation which can be particularly useful with marginalized learners and across cultural contexts.

The report by Staus et al. encourages further work to address the challenge of the ceiling effect which makes it difficult to measure impact of a program when participants already have highly positive attitudes or advanced knowledge.

Outcomes

It is useful to document factual learning outcomes of informal education opportunities. This can be difficult, especially in venues or programs that provide optional activities, because of the large impact of individual motivations that lead to unique experiences for different visitors. Nonetheless, even after a single outing to a science center with many exhibits, Solis et al. were able to document that visitors gave more correct answers on a quiz about the physics content that was illustrated in the center, independent of age and gender. Carson et al. also note increased learning of science content after participation in a citizen science program where participants contributed to new knowledge related to a local issue—the environmental impact of dredging in a harbor.

Other positive outcomes documented in this Research Topic include enhanced science identity as described above, increases in positive attitudes about science and self-efficacy (Sripaoraya et al.), positive emotions about science (Richard et al.), positive environmental attitudes (Carson et al.), and development of skills (e.g., Berg et al.).

Learning science outside of school settings may enhance critical thinking, social learning and other twenty-first century skills. As learning is cumulative, it may not be surprising that few students reported increase in something as complex as critical thinking after a short-term program assessed by Richard et al. In contrast, Falk and Meier found increased creativity, STEM interest, and problem-solving skills after a 1-week long, day-camp experience for 10–12 year olds; *out-of-school pre-camp experiences* was the factor that explained the greatest proportion of variance in those participants' outcomes.

Longer-term impacts of participation in learning opportunities is a challenging but important aspect to measure. Positive longer-term impacts were noted in reports by Carson et al.; Cisneros et al.; Falk and Meier; Forist et al.; Howitt and Rennie; Sripaoraya et al. For example, Forist et al. note that months after a ranger-led hike in Indiana Dunes National Park, visitors could give examples of dune formation and change, human effects on landscape and findings from a scientific study that had been described.

Conclusions, limitations, and future work

This Research Topic provides insights about design of programs, tools for assessing impact and examples of positive outcomes. Nonetheless, it addresses science learning in privileged situations with a plethora of opportunities for learning. Many of the authors in this Research Topic recognize that even in situations described here, with diverse opportunities for science learning, those opportunities are not necessarily equitably accessed by people from diverse backgrounds and abilities. Some authors have recommended design options to improve equity. Future opportunities for science learning with different audiences could explore diverse communication avenues such as gaming and traditional knowledge. In this Research Topic, program and exhibit characteristics which enable different visitor experiences and learning have been elaborated, providing foundations for further work.

Author contributions

NL drafted the manuscript. All authors contributed, edited, and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Role and Value of Out-of-School Environments in Science Education for 21st Century Skills

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The global "wicked" problems we face in the 21st century call for 21st century competencies. The formal education system is hard pressed to foster these competencies within the science curriculum. Accordingly, we argue that out-of-school science education can function as an alternative pathway to 21st century competencies among learners. We present four distinct community case stories on teaching science in out-of-school environments and link them to a number of key challenges linked to achieving 21st century competencies. Natural history museums have been the foundation of science for four centuries and have served as the basis upon which nomenclature of all living species and the concept of evolution has been developed, hence our first case takes place within this frame. Without fieldwork natural history museums would not have any collections and Case 2 takes us out there where it all begins. Humans affect the entire globe and all living matters. Case 3 tells the story of how waste becomes authentic and debatable during a visit to a wastewater plant. Finally, new technologies in the service of natural science is the scope for Case 4 where students collect and analyze their samples of eDNA at university lab facilities in collaboration with scientists, generating valuable real data for research projects. We summarize by discussing how, to meet the challenges of the future, there is a need to strengthen the content and context of curriculums as well as the skills of the learners within natural sciences. The four cases address different themes and skills connected to the highly complex problems like climate change and loss of biodiversity, that may be difficult to comprehend for the greater public but are urgent to teach the adults of tomorrow.

Keywords: science education, 21st century skills, out of school environments, informal education, science engagement, participatory science

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INTRODUCTION

As humanity faces a range of economic, environmental, and social "wicked" problems that are increasing in severity, attention turns to education as a crucial means of preparing us for a more sustainable future (Holfelder, 2019). The uncertainty of the 21st century calls for 21st century skills, i.e., problem solving, critical thinking, communication, collaboration, and self-management [National Research Council (NRC), 2012; Organization for Economic Co-operation and Development (OECD), 2018]—cross-cutting competencies that do not always sit comfortably within the boundaries of formal curricula and subjects, nor within the rules and norms that govern practice in schools and classrooms. Specifically, the OECD Education 2030 Working Group identified five common challenges to the formal school system that hinder or constrain the translation of these competencies into education practice: 1) Curriculum overload, 2) Time lag between curriculum reform and implementation, 3) Quality of content, 4) Lack of equity, and 5) Non-alignment with existing teaching and assessment practices. Even though efforts are being made to address these challenges by gradually changing curricula and education systems in different countries (OECD, 2018), we suggest here that out-of-school science education offers an alternative pathway toward promoting 21st century skills.

By out-of-school science education environments we are referring not just to institutions such as museums and science centers, but also to fieldwork localities, industry, research laboratories or community activities. These environments exist independently of the school system, and accordingly, are not governed by the rules of that system. In the following we will discuss and substantiate how experiences in out-of-school science education environments have renewed relevance in terms of promoting the global transition to sustainability (cf. Xanthoudaki, 2015; Achiam et al., 2021). First, we briefly discuss the challenges identified by OECD Education 2030 of making 21st century competencies actionable in school science and outline how out-of-school contexts might overcome these challenges. Then, we provide four case studies that exemplify our arguments in different and complementary ways. Finally, we discuss the implications of our thesis for science education outside school.

Operationalizing 21st Century Competencies

As scientific knowledge and know-how accumulate, school science curricula are increasingly suffering from overload. This presents an important challenge to making 21st century competencies actionable, because students do not have the time to master the relevant disciplinary knowledge (OECD, 2018). A solution that has often been applied to this challenge is problem-based learning, an instructional method that employs complex, real-world problems to structure learners' self-guided and collaborative identification and acquisition of relevant and operational knowledge (Hmelo-Silver, 2004; Gilbert et al., 2011). Well-designed problems guide learners to use relevant knowledge and skills to infer fundamental principles and procedures for themselves (Prince and Felder, 2006), rather than requiring them to sift through an overloaded curriculum to determine what is applicable. In the following, we illustrate how out-of-school science environments (in particular Case 3, a wastewater treatment plant) are ideal settings for problem-based learning, because they are situated in society and in many cases deal directly with the tangible, real-life, often ill-structured problems of that society.

Another challenge to the operationalization of 21st century skills in school is the time lag between the intentions of a curriculum and its implementation and impact (OECD, 2018). This gap is caused by the delay from the publication of scholarly knowledge (whether related to science or science education) to its introduction in curricula and textbooks (cf. Quessada and Clément, 2007; Clément and Castéra, 2013). This delay is not present to the same degree in out-of-school science environments because they are often places of on-going scientific research, for instance museums or research laboratories. Accordingly, they have direct access to cutting-edge scientific knowledge and practice and can engage learners in this 'science in the making' rather than the "ready-made science" (cf. Latour, 1987) of the formal science curriculum. We suggest that because outside school, teaching is driven by current cases and problems that are not linked to formal textbooks, the problem of time lag between curriculum reform and implementation is alleviated here. In Case 4, we Illustrate how cutting-edge science motivates students to engage with science.

If the curriculum is overloaded and out of date, as discussed in the preceding, it is not difficult to imagine that learners will also perceive it as being of poor quality. This stands in the way of the acquisition of deeper understanding (OECD, 2018). We suggest that out-of-school science environments can help alleviate this problem by placing scientific material and ideas within an explicitly real-life context that is relevant to students from diverse backgrounds. Ideally, this context would require learners to reflect on their available knowledge in the context of authentic data and scientific methodology (Gilbert et al., 2011) and in doing so, answer the questions for themselves of "why do I have to know this?" and "will I ever use this again?" (Taasoobshirazi and Carr, 2008). We demonstrate the potential of learning in context in Cases 1 and 2.

Although it is an important objective of science education to produce innovators, too often the benefits of social, economic, and technological innovations are unevenly distributed (OECD, 2018). Even though objectivity is an important part of the self-image of the natural science disciplines (Reiss and Sprenger, 2017), research shows that science curricula may promote inequity by implicitly sanctioning certain identity performances among learners while discouraging others (Ulriksen, 2009). We suggest that out-of-school science environments can prompt constructive ruptures from the behavioral norms of the everyday science classroom, allowing learners to negotiate and challenge stereotypical "ways of doing" (Silfver, 2018). We argue that all the cases we present here have this potential, and we return to this point in the discussion.

Finally, the OECD Education 2030 Working Group (2018) pointed out that 21st century competencies are not easily measurable with the assessment tools that are available to the science education community today (see also Dolin et al., 2018). This hinders the constructive alignment (cf. Biggs, 1996) between 21st century curriculum objectives, instructional design, and assessment, thus constraining the successful implementation of teaching for 21st century skills in schools. Although we are not suggesting here that out-of-school science education environments should become places of assessment, we agree with scholars who point out that assessment of competencies should focus more holistically on scientific practices prompted in authentic, real-life contexts (Rönnebeck et al., 2018; Ropohl et al., 2018). Out-of-school environments might thus provide valuable input to research in what constitutes good practice in the assessment of 21st century skills, because they are neither overly focused on specific disciplinary skills, nor do they prompt completely generic competencies (cf. Nielsen et al., 2018).

There are a few basic components that must be addressed for students taking sciences classes. Science is all about describing what we see and to understand the linkages between the various boxes that make up the system that we are studying as well as the cause and effect of changes we observe within the system. Three basic questions must be addressed: 1) What is the problem or question we are aiming for to answer? 2) Why is it important or interesting? 3) How can we solve the problem or answer the question? Scientific methods are only valid if they can be reproduced by others, i.e., they need to be standardized.

CASE 1: NATURAL HISTORY MUSEUM

The first case we present takes place in a natural history museum, defined in general by the three museum “pillars” of collections, research and dissemination (NATHIST, 2013). Natural history museums reflect the ongoing practices, discourses, and ways of reasoning of natural history in order to understand the interconnectedness of living things and the environment (King and Achiam, 2017). Natural history collections-based research in museums has thus contributed to our understanding of several of the global problems we are facing, e.g., the biodiversity crisis or the global pandemic (Suarez and Tsutsui, 2004; McLean et al., 2016). In the following, we illustrate how this case addresses the curriculum challenge identified by OECD (2018) of poor-quality curriculum.

Setting the Scene

Naturama is one of three classical museums of natural history in Denmark. In 2017 Naturama was part of an interdisciplinary education project with the Department of Mathematics and Computer Science at the University of Southern Denmark. For many students, mathematics can be difficult (Salout et al., 2013; Murphy, 2017), hence the idea was to teach mathematics by addressing real-life examples with appealing hands-on activities. These examples were selected to help learners grasp how mathematics can support new insights as well as an understanding of the world around them.

The aim was to use the natural history setting and narrative to frame the teaching of mathematics using museum specimens. The basic mathematical tools in the present case story are measurements, statistical descriptions of the data and statistical analytical tools to test for differences between subsets of data collected during the event. The project consisted of four independent visits that focused on 1) Evolution, taxonomy, variation, and scientific measurements; 2) Comparative physiology; 3) Sexology and reproductive strategies; 4) Population biology, demography, and population estimates. Here, we focus on the first visit. Without careful studies of museum collections, Linné, Darwin, Wallace and others would not have been able to develop taxonomy and the theory of evolution, upon which the understanding builds of species differentiation and their adaptations to specific habitats and its biodiversity. The first visit thus embodies content that is specific and essential for natural history museums.

Case Description

Evolution explains the origin of today’s life on earth and is overwhelmingly accepted in the Scandinavian countries (including Iceland) and in most European countries (Miller et al., 2006); however, a large part of the world’s population does not see evolution as the mechanism behind speciation. In fact, roughly a third of all Americans believe that humans have existed in their present form since the beginning of time (Berkman et al., 2008; Cooperman et al., 2019). Hence teaching evolution is highly relevant on a global scale.

The visit by the high school class begins with an introduction to the mechanisms behind evolution. Then, a guided tour in the exhibition allows the learners to engage with the various animal species on display and their evolutionary links. In the main part of the visit, learners engage in hands-on measurements and non-metric analyses of specimens from the museum’s collections. The exercise also illustrates how data collection is affected by the observer, and how mathematics is required as a scientific tool to handle these variations.

A collection of mink skulls (*Mustela lutreola*) is examined using calipers. Several students take the same measurements (e.g., length of skull) which produces the inevitable variation in data obtained by different examiners on the same specimen; this variation serves as a basis for calculating mean values and variance. The objective is for the student to be able to test whether there are significant differences in the precision of specific measurements taken, and whether some measurements have a smaller variance than others, hence being more robust as characters. As the skulls are sorted by sex, sexual dimorphism can be examined as well as relations between related measurements e.g., length vs width.

Another way of describing and analyzing differences between individuals is to register, count or score nonmetric variables and symmetry. Nonmetric variables are recorded without the use of e.g., a caliper but can be e.g., the number and placement of foramen (nerve holes) on the skull or a subjective ranked score of asymmetry. These are phenotypic characters reflecting the genetic variation of a trait. Symmetry has in some studies been regarded as an advantageous trait among males in the competition for females and hence their fitness (Møller, 1992; Møller and Pomiankowski, 1993). For this exercise students are presented with a collection of male roe deer skulls with antlers. The left and right antler are scored for their asymmetry, and the volume (metric variable) of the antlers is measured by submerging the antler (from tip to the base) in a water container with volume markings. In the discussions of these examinations, factors affecting the size and shape of the antlers are considered, including the age of the individual and the quality and calcium content of the food. Asymmetry is not just affected by genes; injuries acquired during the growth of the antlers can also deform them and cause asymmetry. Accordingly, there may be annual variations within a single individual.

What Have We Learned?

This exercise presents the learners how to look for similarities among different species in the exhibition and to group them within taxonomic terms. As a scientific tool measurements are important to describe a species, but not every character is suitable to measure for descriptive purposes. By examining and discussing the underlying variables affecting their obtained data the students gain a valuable mathematics-based perspective on how to approach scientific data.

CASE 2: FIELDWORK

Field work is the study of the environment that takes place outdoors and uses the environment as a learning resource (Scott et al., 2006). It studies the complex of variables that are involved in the interrelationships between living things and their environment and offers a genuine open-ended context for scientifically authentic work, because neither learners nor educators know the answers to the questions that it prompts (Lock, 1998). Field work can encompass inquiry at many different levels, from large-scale composition and characteristics of biomes to the small-scale habitat of, for instance, cow dung situated in the different microhabitats of a shady forest or a sunny heathland. In the following, we illustrate how Case 2 can help counteract the experience of a poor-quality science curriculum by providing learners with an authentic, problem-based context.

Setting the Scene

Geo and Bio Science Center South is an initiative that offers free high-quality education in suitable nature areas with the aim to increase students' interest in the natural sciences. The Center offers a variety of different interdisciplinary courses on biodiversity, ecology, evolution, sustainable food production, climate change, geoscience, and landscaping, aimed at students from middle school to high school. Within each topic, different themes or exercises are offered as "building blocks", and it is common practice to mix exercises from different courses to match the visiting teacher's wishes for the day and the curriculum.

The programs are conducted outdoors, in nature, to prompt participants to follow their own lines of inquiry, and to provide an authentic real-life setting for those inquiries. For instance, in the case of the biodiversity program that we discuss in the following, different forest plots give participants the opportunity to infer what factors influence biodiversity by assessing the biodiversity within these plots. For instance, forests can play an important role in storing carbon dioxide as well as securing a high biodiversity, but these aims may not necessarily go hand in hand as forests may be used to produce timber for e.g., houses, which will store carbon dioxide on the long term, but support a less rich biodiversity. In this way, participants are prompted to qualify their understanding of the present biodiversity crisis.

Case Description

After a brief introduction to the purpose and program of the day the students are taken on a walk in the forest to monoculture tree plots, e.g., young and older beech plots, and conifer plots. They qualitatively examine the biodiversity of the trees by collecting as many different leaves as possible within five minutes. All leaves are then lined up and divided into functional groups, and the total number of species is counted. The result is usually 8–10 species.

The next exercise quantifies the invertebrate diversity on the forest floor. As the method has to be standardized in order for comparison, we discuss the various methods available depending on the specific scientific question raised by the teacher and the composition of the study plot. The students are responsible for choosing their own sampling site within the well-defined monoculture in focus. Using a simple guide and illustrated key, the students can identify most of the invertebrates, at least to the level of order. The number of different species and "species groups" is noted.

Finally, to illustrate that different types of habitats, even those in close proximity to each other, can have remarkable differences in biodiversity, the exercise moves further into the woods to a patch of wild forest. Here, the exact same surveys are carried out. The biodiversity of trees and bushes in the wild forest plot is usually 15–20 species, and the number of different invertebrates is also much higher. These different forest plots clearly illustrate the concept and link between biodiversity and habitat heterogeneity. In addition, the importance of variation in structure, ages and plant species for the insects inhabiting the forest becomes evident. The students are asked to discuss and explain how this correlates with their results, and obvious sources of error are discussed to help the students reflect on the method used and qualify their understanding of the gained results.

What Have We Learned?

At the end of the program, the students discuss approaches to the challenges of climate change and the biodiversity crisis. Most of the students usually agree on the needs for reducing the area of agricultural land, increasing the area of forests, particularly wild forests. At this point they might also discuss concrete actions that they themselves can carry out to take ownership and responsibility to meet the challenges of the future.

CASE 3: WASTEWATER TREATMENT PLANT

The third case is set at a working wastewater treatment plant and exemplifies an industry-based science education situation. Unlike schools who are constrained by curriculum requirements, industry-based science institutions represent applied, real-life science that does not need justification. Research shows that the industrial context can indeed provide learners with compelling authentic problems (Erhart et al., 2016) that motivate them to engage and ultimately envision science as a career pathway (Porter et al., 2006). In the following, we show how Case 3 provides an authentic framing of real-life science problems, whilst sidestepping problems of an outdated curriculum.

Setting the Scene

Being alive always creates waste of some sort. But human waste products have changed the course of life on Earth. Waste products and pollution that originate from all the various goods from e.g., clothes, smartphones to space rockets can be hard to grasp, but focusing on daily waste that we all process and get rid of through the sewer system can be very present and a real eye opener.

In Denmark, wastewater is treated mechanically, biologically or chemically at more than 825 wastewater facilities across the country. These are owned by the municipalities but are driven as private companies. The primary focus is to clean wastewater and secondly to produce energy from the waste products. Some of these companies additionally offer guided tours of their facilities as well as topical hands-on activities for school groups. Biofos is such a company and offers programs to involve students from middle school to high school in the interdisciplinary science behind the treatment of wastewater.

Case Description

The visit starts with an indoors presentation on how the sewer systems and treatment plant are connected. It describes the different steps in the treatment process, using live microscope images of bacteria and microorganisms that support the cleaning of the water. It explains how bacteria are crucial to the functioning of our bodies, in food production, and in the degradation of biological material. The setup enables the students to discuss the kind and amount of wastewater that they produce daily and explore the science behind wastewater treatment. A simple experiment shows the degradation of sugar by a mix of water, sugar, and yeast placed in a bottle with a balloon on top. The yeast decomposes sugar to water and carbon dioxide (and a small amount of alcohol). An advantage is that the students can easily reproduce the experiment in their own school laboratory, for instance for a school report.

Where the sewer system enters the facility, the color of the wastewater is dark brown, the smell is unpleasant, and occasionally some of the more solid waste products such as diapers or sanitary napkins are visible. Midway, the wastewater has a high concentration of bacteria, and the water looks viscous, almost like chocolate milk. The smell has diminished. At the last stop, the wastewater is clear and odorless and looks almost like drinking water.

What Have We Learned?

Prior to the visit, the attitude of many students is that wastewater is disgusting and smelly; indeed, this is also the reality they encounter upon their arrival. Their step-by-step experience of wastewater treatment confronts them with the magnitude of human waste (in the thousands of cubic metres!), and the volume and capacity of the treatment plant. They gain insights into how "wastewater" can be seen as a valuable resource, as most of the residual product is used to produce biogas and heat. These new insights allow students to have qualified discussions of how climate change and heavy rain in cities affect those cities, the treatment plants, and the infrastructure. A visit like this does not follow the curriculum of school subjects (e.g., physics, chemistry, or biology) but focuses on a real-life problem that transcends disciplines. This is the privilege of out of school service, and the feedback from students and teachers indicates that they appreciate the close link between theory and practice.

CASE 4: DNA LABORATORY

The final case presented here combines many of the features of the preceding three cases, namely a natural history museum framing, field work, and an authentic laboratory setting. However, what we wish to emphasize is the cutting-edge nature of the work that goes on in the program. Research suggests that an immersion into the continuous development of scientific knowledge is necessary in the formation of scientifically literate citizens; yet much science inside and outside schools is presented as objective and finished (Hine and Medvecky, 2015). In the following, we demonstrate how the close proximity between science research and science education in Case 4 allows learners to engage themselves in uncertain science in the making, thereby acquiring valuable experiences of scientific methodology and its implications.

Setting the Scene

All living organisms release DNA into their environment. This can be skin cells, hair, eggs, feces, bones, etc. Such DNA is termed environmental DNA (eDNA) and detecting it in the environment is a novel non-invasive method of evaluating the presence of a species. Using eDNA has over the past couple of years been widely implemented in biodiversity surveillance projects across the world. The invisible DNA is detected using molecular "fishhooks" called primers. Primers are sequences of DNA which target specific species.

Case Description

The Natural History Museum of Denmark (NHMD) initiated a citizen science project in 2012 as a recurring opportunity for high-school students. The project, DNA and Life, creates a learning environment where high-school students work directly with researchers in detecting species using a cutting-edge eDNA research method. While students *contribute* water samples, they themselves collect from their local areas, they engage in authentic *collaboration* (cf. Bonney et al., 2009; Sandahl and Tøttrup, 2020) with researchers in the production and analysis of data to find answers to scientific questions (cf. Irwin, 1995) that can be used in species management.

Specifically, the objective of DNA and Life was to engage high-school students in hands-on testing of eDNA assays for environmental monitoring of freshwater and marine organisms in Denmark. The project aimed to increase high-school students' knowledge about the eDNA method; however, the main focus was to enhance students' understanding of the scientific process and in particular, their understanding of science in the making. However, another factor that gradually became apparent was how meeting and collaborating with real scientists was highly motivating for the students (Sheard et al., 2018).

DNA and Life allows students to experience the full range of scientific settings, from field work to the laboratory. They can thus follow the scientific process from the macroscopic habitats of living animals to sub-microscopic data observed through advanced methods. In the first step the students choose a local location that they find relevant and interesting. They collect a sample from this location, using a field kit sent to their school containing materials and instructions on handling eDNA. In the second step, the sample is sent to the NHMD laboratory in Copenhagen where it is prepared by technicians. In the third step, students visit NHMD to work with their own sample in an authentic laboratory. Here, the students amplify DNA from specific targeted species. The study design includes three kinds of samples: Two known control samples and one unknown (the students' sample). Using this approach, the project can deliver high quality data based on the analyses of non-professional high-school students.

What Have We Learned?

Evaluations of DNA and Life show that high school students can engage with the eDNA method, and that they generate results that can be used to monitor aquatic species. The students' cumulative success rate was high, but individual analyses often failed. We argue that both kinds of outcomes are important for understanding science in the making; certainly, students learned from the group discussions of both successes and failures following the laboratory work. In fact, the project design facilitated these discussions by including the testing of both control and intervention samples, even if the primary reason for this was to achieve research quality data. That the data resulting from their work was used for subsequent research and species management was another motivating learning outcome for the students.

DISCUSSION

We have offered our thoughts on how out-of-school science education can help learners acquire 21st century skills. Even so, there is nothing new about 21st century skills; what is new is perhaps the extent to which a rapidly changing world requires these skills. Pressing wicked problems such as climate disruption, biodiversity loss, deforestation and pollution gives a new sense of urgency to science education, which must provide actionable understanding of natural processes, links between species, and evolutionary mechanisms. This understanding is only enriched by knowledge and skills acquired in other contexts and thus emphasizes the value of the interplay between the science learning contexts.

We have argued the importance of out-of-school experiences for achieving 21st century skills and ultimately, contributing toward a more sustainable future. In particular, we have argued that out of school science education addresses the challenges identified by the OECD Education Working Group (2018): We claim that out of school science education can facilitate a more comprehensive understanding of the world around us and of why knowledge is crucial in making the right decisions. In the following, we discuss these points in further detail.

As science communicators and educators, we have witnessed firsthand how constraints and requirements from broader society have led to science curriculum overloading. The OECD (2018) recommendation of shifting the focus from "more hours of learning" to "more quality learning time" speaks directly to the cases presented here, which collectively offer high-quality learning driven by immersive hands-on activities, authentic situations, and "real life challenges and questions. Defining and implementing a new curriculum takes time. As discussed in the preceding, the process is constrained by a number of societal requirements, and thus risks rendering the new curriculum out of phase with rapidly developing socioscientific issues and their solutions. Each of the presented case stories included high priority content such as evolution, biodiversity, pollution, reuse of bioresources, climate change and cutting-edge techniques like eDNA. At the same time, topics like evolution, pollution, climate change and DNA are all to be found within the complex wicked problems that contain the risk of non-specialists to be left in a limbo of disillusion. Thus, the OECD recommendations for the design of learning processes and situations should be challenging and enable deep thinking and reflection (OECD 2018). In this respect topics that are directly relatable to the students and their interests comprise the easiest path to their engagement. This is evidenced by movements such as Greta Thunberg's Fridays for Future, which clearly address a wicked problem that young people—the adults of tomorrow—are concerned about and demand solutions for.

The massive global problems we are facing drives home the point that all students should have equitable opportunities to acquire the basic skills of the 21st century. Inequity may originate and manifest itself at many levels, and even within prosperous countries, access to high quality education varies based on gender, ethnicity, ability, region and socioeconomic status. We argue that out-of-school science education provides learners from across these spectrums with opportunities to escape the often gendered, raced, classed scripts of school science to negotiate new ways of interacting with science that are personally meaningful (Silfver, 2018; Nicolaisen and Achiam, 2020), and we believe further research would be able to document such negotiations in the four cases discussed here.

However, an alternative pathway to providing equitable out-of-school science experiences, that has become apparent in the ongoing covid-19 pandemic and related travel restrictions, is the provision of virtual programs and visits. Virtual teaching cannot, of course, provide direct hands-on experiences, but have other strengths, for instance allowing learners to interact with otherwise non-accessible virtual objects and experiments (e.g., The Digital Atlas of Ancient Life, https://www.digitalatlasofancientlife.org/), or linking up with scientists all over the world. Fielding et al. (2019) described several cases where students were connected to ongoing research, even to research vessels in the middle of an ocean. Wildlife conservation classes at the University of Southern Denmark have likewise brought international conservation specialists from South Africa and Australia into an out-of-classroom event at a Danish zoo, giving students the opportunity to interact with the first authors of their hand-out references via Zoom (February 25th, 2021, Dalia A. Conde, pers. com).

For many learning environments, curriculums are often tied to the same textbooks for many semesters as teachers may be faced with work overload. So maybe at the bottom of the wicked problem of how to create curiosity, motivation, inspiring engagement among learners in a stimulating quality driven learning space is linked to the authenticity of the themes and context taught.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

TB and MA designed the concept and outline of the manuscript. All authors wrote sections of the manuscript and contributed to the manuscript revision, read, and approved the submitted version.

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Families Visit the Museum: A Study on Family Interactions and Conversations at the Museum of the Universe – Rio de Janeiro (Brazil)

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In this quantitative and qualitative study, we present our analysis on the interactions and conversations of ten families during a visit to the Museum of the Universe, at the Planetarium Foundation of the City of Rio de Janeiro (Brazil). The study of conversations provides a considerable opportunity to address gaps in our current understanding on how families interact and learn in museum environments. The visits were recorded using a subjective camera, and the audiovisual material was analyzed based on a research protocol that combines theoretical and empirical aspects of the visitors' museum experience. We identified that most of the interactions during the visit occurred between family members and between them and the exhibition, through interactive activities and moments of contemplation. Parents/caregivers played an important role in maximizing the children's learning opportunities as they interacted and talked about the exhibits. The conversations were related to science topics, especially astronomy, as well as aspects on how to operate the exhibition modules. The results suggest that the Museum of the Universe has become a platform for families to share experiences, discuss and develop specific ideas, knowledge and concepts about astronomy, enriching the group members' awareness.

Keywords: science museums, informal education, family interactions, conversations, astronomy

INTRODUCTION

Visits to science museums are highly complex and potentially rich experiences to study family interactions, actions, conversations and learning (Callanan, 2012; Haden et al., 2014; Shaby et al., 2019). Many of the phenomena, activities and skills related to science learning are observable interactions in museum spaces, such as identification, designation, observation, comparison, generalization, analysis, scientific reasoning, abstraction, peer collaboration, conceptual change, motivation, engagement, identity and metacognition (Allen and Gutwill 2016). In this regard, investigations into the variety of cognitive and social interactions between visitors, between a visitor and an activity, object or experience in science museums are highly revealing about the learning process of families (Davidsson and Jakobsson, 2012; Shaby et al., 2019).

Family learning in a museum is a social and collaborative activity, in which the group works together to build a meaningful experience, learn from each other and develop knowledge while interacting and engaging in a dialogic exchange (Ash, 2003; Ellenbogen et al., 2004). Falk and Dierking (2002) emphasize that the interactive experience in the museum is influenced by three contexts: sociocultural (visitors museum experiences), physical (architecture and organization provided by the museum space) and personal (motivation and expectation, knowledge, experience, beliefs, past interests).

Dierking et al. (2001) define family learning as the process that incorporates social ties and the family's experience with objects, ideas and situations, in essence, the family narrative. As this definition suggests, based on a sociocultural perspective, the developed museum experience is connected to the visitor's life experiences (Almeida and Martínez, 2014). Research investigations with this focus has directed studies of the area beyond what visitors learn from a museum visit and have expanded the investigations to understand what visitors actually do during the visit, examining the visitors' interactions with each other, with the team and exhibitions (Davidsson and Jakobsson, 2012).

According to Ash et al. (2012), interaction is an important part of the museum experience and is fundamental to describe and identify consistencies in how visitors use and engage with the resources of their complex social and material world that integrates actors and objects. In the present article, we understand that interaction comprises human activities, including non-verbal interactions and the relationships established between visitors of the same group, between visitors and the museum staff and between visitors and the exhibition (objects, exhibition modules and themes covered) (Davidsson and Jakobsson, 2012; Massarani et al., 2019c; Shaby et al., 2019).

Family interactions in museums provide evidence about the wide range of personal and cooperative learning strategies (Ellenbogen et al., 2004). Some authors are devoted to investigating the visitors' engagement and learning in museums quantifying their length of stay in the exhibition modules and frequency of physical and verbal behaviors (Block et al., 2015). Others, like Brown (1995), show that parents can take a passive role - monitoring children while interacting, or active - engaging the children in the themes of the exhibitions. Szechter and Carey (2009) demonstrate that it is the children who choose the exhibitions for their families and who most control the interactive devices. Researchers like Riedinger (2012), Zimmerman et al. (2010) also explain that parents tend to significantly influence how children interact with exhibitions and what they learn during visits.

Recent studies have placed considerable focus on the study of conversations in order to better understand family learning. Conversation stimulates thinking and, whether developed with other people or with yourself, it is an essential process in the acquisition of new knowledge and in the expression of feelings (Wagensberg, 2005). As a result, some aspects of the visits have been highlighted, such as which elements of a science exhibition stimulate conversations and how families make connections with scientific content (Allen, 2002; Haden et al., 2014; Callanan et al., 2017); the role of explanation and scientific reasoning in conversations between parent-child (Crowley et al., 2001; Tare et al., 2011) and how families make sense of science-related experiences through conversations about exhibitions and expository modules (Benjamin et al., 2010; Zimmerman et al., 2010; Jant et al., 2014).

For example, Tare et al. (2011) investigated how parents support their school-age children's learning–seven to 12 years old–during a visit to the Explore Evolution exhibition at the Natural History Museum in the Midwest (Illinois, United States). The conversations of 12 families were transcribed and classified into different codes, divided into two main blocks: 1) evolutionary reasoning and intuitive reasoning, and 2) types of conversations. As a result, the authors indicate that parents provided great support for their children's learning about the science process and scientific content, since the expressiveness of the most frequent explanatory codes was to describe scientific evidence (37.3%), ask factual questions (14.2%) and provide causal explanations (13.9%). Most of the conversations about evolution were provided by the text of the exhibition (12.8%), suggesting that the available texts are an important source of information for families. The study also provides evidence that the parents' conversation style is reflected in the children's words. The greater the frequency of explanations and the use of evolutionary terms expressed by adults, the greater the presence of explanatory conversations and the use of terms in the children's words, which indicates the occurrence of a dialogic exchange between parents-children.

Another study example on conversations relevant to science learning was carried out by Callanan et al. (2017) with 82 families, which included children between three and 11 years old during a visit to the Mammoth Discovery Exhibition regarding mammoth bones at the Children's Discovery Museum in San José (California, United States). The authors investigated three main issues: 1) the types of language parents use to involve and promote the construction of meaning in children regarding the exhibition; 2) how an activity individually prepared for the parents changes their language with the children at the exhibitions, and 3) how the conversations of parents-children are developed, comparing different proposals of the exhibition–authentic fossils, replicas of bones and interactive activities with replicas of bones. The results suggest that parents use different types of conversations and the difference is related to the nature of the exhibition, and in that study the interactive activities were more stimulating for science conversations and for the construction of meaning. Comparing the groups of parents who received guidance to establish a focused discussion compared to those who did not receive such guidance, the authors point out that the children's conversations were more engaged in the first groups, given the parents' frequency of critical thinking questions. However, the authors caution that questions can encourage children to engage, however providing explanations can reduce an engaged conversation. They also bring evidence that conversations with personal connections may be more important for the children's involvement and understanding than the parents' scientific explanatory conversation, behavior that was more strongly related to the parents who were not prepared to initiate conversations with the children. This result is consistent with the work of Benjamin et al. (2010), Jant et al. (2014), which show important associations between personal conversations and children's learning.

Similarly, Zimmerman et al. (2010), who accompanied 15 families visiting the Pacific Science Center in Seattle (Washington, United States) through ethnographic and analytical discourse methods, concluded that the parents showed the children how to use evidence, directed the children's attention to relevant aspects of the exhibition and provided connections with previous knowledge and experience. Family members used their previous knowledge and experience to make sense of the material presented at the exhibition through strategies such as shared memories, storytelling and jokes and the use of analogies. These strategies helped parents to develop children's learning during the museum visit.

In summary, these studies reinforce that families shared knowledge, experiences, beliefs and values that influence the museum experience (Falk and Dierking, 2000; Ellenbogen et al., 2002). They demonstrate that, on a visit to the science museum, family members talk about topics that are relevant to their new and shared learning experiences. This is because during the visit to exhibitions, the conversations are part of a process, which may have started at an earlier time, restarted at the exhibition and could possibly be incorporated in future conversations (Crowley and Jacobs, 2002; Ellenbogen et al., 2002). In addition, the questions and explanations seem to influence how parents-children engage with the exhibition and get involved with the content.

Taken together, these and other studies provide valuable information, but also point to an important gap in the area: the need for more detailed studies on conversations and interactions during family visits to science museums from a Latin American perspective, since most of them took place in North America and Europe. With few exceptions, some investigations have explored family learning experiences from the perspective of socio-cultural theory (e.g., Bizerra, 2009; Briseño-Garzón and Anderson 2012; Rufato and Bizerra, 2014; Cerqueira et al., 2017; Scalfi, 2020). Another gap in the international literature, and particularly in the Brazilian literature, is the interaction of families with astronomy themes in places such as museums, planetariums and astronomical observatories. Astronomy is a science that affects the imagination of children and adults, showing great potential to arouse interest in science (Falcão et al., 2013). However, notwithstanding the consolidated literature on these sites as environments for teaching astronomy, especially for school groups and focused on formal education (e.g., Rusk, 2003; Langhi and Nardi, 2012; Almeida et al., 2017), thus far, there are few studies on how family learning ensues.

Based on the above, in this study, our objective is to understand the learning experience of families visiting a science museum that focuses on astronomy, highlighting the types of interaction and the conversational contents. This study collaborates to understand the family learning in non-formal education environments in the Brazilian context, providing support to expand and deepen the growing literature on families' interactions and conversations regarding practical learning experiences in science museums.

METHODOLOGY

To meet the proposed objective, an exploratory study using quantitative and qualitative methodological approach was carried out to study family interactions during a spontaneous visit to the Museum of the Universe, at the Planetarium Foundation of the City of Rio de Janeiro (Brazil). The methodology employed has been used to develop research in the field of education in museums, as well as by the research group, based on this study, which aims to understand the processes of the experience of visitors to science museums (Massarani et al., 2019a; Massarani et al., 2019b; Massarani et al., 2019c). This study was approved by the Ethics Committee of the Oswaldo Cruz Foundation (CAAE 10663419.0.0000.5241). All participants consented to their participation through the free and informed consent term, which had information about the research procedures and objectives.

Study Location

The Museum of the Universe is located in the Gávea neighborhood, in Rio de Janeiro (Brazil), and receives audiences from different regions of the city and the state. The mission of the museum is to communicate astronomy and related sciences, integrating science, education and culture through an innovative approach, receiving an average of 267,000 visitors per year.

The Museum of the Universe, which is integrated into the structure of the Planetarium, consists of three floors. The first floor comprises the long-term exhibition, which has several expository, interactive modules, with multimedia resources, models, immersive experiences, divided into five areas: "The Earth in Movement" ("*A Terra em Movimento*"), "What Time Is It?" ("*Que Horas São?*"), "Astronomy Yesterday and Today," ("*Astronomia Ontem e Hoje*"), "We and the Universe" ("*Nós e o Universo*") and "School Spaceship." ("*Nave Escola*"). The second and third floors are for short-term exhibitions that during data collection were: "A giant leap: the journey to the Moon" and "The dazzling Universe" (**Table 1**). The first commemorated the 50th anniversary of man's first landing on the Moon, the second honored the 50th anniversary of the European Southern Observatory (Fundação Planetário, 2020). During the research period, the exhibitions did not have museum educators to serve the public.

Procedures and Participants

In this study, a family is understood as a group of individuals biologically related or who considered themselves as a family by affective ties (Briseño-Garzón and Anderson, 2012). The family groups consisted of up to six people and with at least one child

TABLE 1 | Themes covered in the exhibitions of the Museum of the Universe.

Location/Thematic area	Description
1st floor - long-term exhibition	
"The earth in motion"	It introduces the concepts related to the phases of the moon, eclipses, seasons, apparent movement of the sun and tides.
"What time is it?"	It brings astronomical information to discover the location of a point on the surface of planet earth, measurement of time and time zones.
"Astronomy yesterday and today"	In a timeline, it addresses the history of astronomy and the contribution of astronomers, physicists and mathematicians to the area.
"We and the universe"	It introduces concepts of cosmology such as geocentrism and heliocentrism.
"School spaceship"	An installation set as a spaceship that suggests a journey through the universe addressing topics such as the solar system, space research and the evolution of life.
2nd floor - short-term exhibition	
"A giant leap: the journey to the moon"	It features panels and videos about the space race and the apollo program.
3rd floor - short-term exhibition	
"The dazzling universe"	It highlights 38 photographs that illustrate space discoveries and the equipment that enabled expanding astronomical knowledge.

between five and nine years old. The criteria used was designed to optimize the recording with sufficient audiovisual data quality in the interactive process and enable conversations with the children. In this study, the children's age range is representative of childhood, encompassing preschool and school-age children, in order to capture the internal logic of the psychic development process (Elkonin D. B., 1960). It is after preschool age that a child is able to share his impressions with adults, adopting coherent and explanatory language and, at school age, this language is more cognizant and intentional and mental operations are improved (Elkonin D., 1960), which favors the dialogic process in the family relationship.

Data collection took place in February and the first week of March 2020, the period when entry to the museum was free. We focused at families who were spontaneously visit to the museum. When approaching the family groups at the museum entrance, the research assistants informed them about the purpose and procedures of the study, as well as about the ethical conduct. When they agreed to participate, an adult member of each group was asked to complete a questionnaire to summarize the participants' socio-cultural profile and habits in relation to visiting museums and cultural centers. The families' visit took place freely, without interference from research assistants who were at a safe distance so as not to compromise the group's interaction. When the families expressed the wish to end the visit, they approached the research assistant to inform him/her to remove the equipment.

To record the museum experience, we used the "point-of-view camera" method (Lahlou, 2011, Glaveânu and Lahlou, 2012; Massarani et al., 2019c; Massarani et al., 2019a; Massarani et al., 2019b) which consists of capturing video audio through a subjective GoPro-type camera attached to the head of one of the visitors during the visit. In this study, one child from each group was asked to use the camera and the visitors had autonomy in their experience, that is, they visited the spaces they wanted and interacted for as long as they wanted, as they would on any other museum visit. Among the limitations of using the point-of-view camera method, we can highlight the fact that visitors have self-awareness that they are using the camera, which can modify their behavior (Glaveânu and Lahlou, 2012). In addition, when children register the visit at the beginning of the records, some of the tend to focus their attention to the camera. However, this behavior is reduced and even disappear during the visit (Burris, 2017). The duration of the visits ranged from 17 to 59 min (average of 35 min) (**Table 2**).

In total, ten groups of families participated in this study, with 16 children aged five to nine years (nine boys and seven girls), one teenager (male) and 19 adults (10 women and nine men). In the applied questionnaires, it was found that eight families resided in the city of Rio de Janeiro, and two in the metropolitan region of the capital - Niterói and São João de Meriti (**Table 2**). Of the groups approached, who had agreed to participate, for personal reasons two of them dropped out during the visit. We reinforce that the decision was respected, and the audiovisual material was not analyzed.

Based on the data collected from the questionnaires, we identified that the families reported having the habit, although not frequent, of visiting scientific-cultural spaces. For example, more than half of families (6) said they visited science spaces, museums and exhibitions more than once a year; the rest of the participants reported visiting this type of space at least once a year. Pertaining to expectations regarding the visit they would make at the Museum of the Universe, the responses highlighted their interest in additional knowledge, with special motivation in teaching something to the children and the search for leisure, entertainment and enjoyment.

Data Coding and Analysis

The analysis of audiovisual data was facilitated by the software program Dedoose 8.0.23, which allows coding the visitors' interactions (bodily, textual and attitudinal actions) simultaneously. As an analysis tool, we used a protocol–developed and validated by the network of researchers involved in the project–which is used to analyze how the experiences are organized in the museum, since it is used in the relationships between three fundamental actors: the exhibition modules, the visitors and the mediators (Massarani et al., 2019a; Massarani et al., 2019b; Massarani et al., 2019c). The protocol is divided into five dimensions (*Conversations, Types of Interaction, Photos, Change* and *Emotion*) and their respective

TABLE 2 | Information about family groups.

Groups	Location	Members	Gender/age	Visiting time
G1	Rio de janeiro (RJ)	3	2♀ (6, 33); 1♂ (42)	51 min 34 s
G2	São joão de meriti (RJ)	4	2♀ (8, 29); 2♂ (12, 31)	37 min 30 s
G3	Rio de janeiro (RJ)	3	1♀ (39); 2♂ (5, 44)	17 min 40 s
G4	Rio de janeiro (RJ)	4	3♀ (3, 8, not informed); 1♂ (41)	39 min 47 s
G5	Rio de janeiro (RJ)	3	1♀ (7); 2♂ (5, 44)	59 min 05 s
G6	Rio de janeiro (RJ)	5	2♀ (20, 40); 3♂ (6, 14, 45)	40 min
G7	Rio de janeiro (RJ)	2	2♂ (7, 33)	25 min 44 s
G8	Rio de janeiro (RJ)	2	1♀ (35); 1♂ (9)	33 min 34 s
G9	Rio de janeiro (RJ)	6	3♀ (7, 34, 64); 3♂ (1, 5, 37)	32 min 07 s
G10	Niterói (RJ)	4	2♀ (2, 39); 2♂ (8, 39)	21 min 41 s

TABLE 3 | Categories *Types of interaction and Conversations*.

1. TYPES OF INTERACTION	
1.1 Visitor-visitor	When visitors interact and chat with each other, regardless of the content of that conversation.
1.2 Visitor-exhibition module	
1.2.1 Interactive activity	The interaction occurs through: Immersion; experimentation; physical interaction (pressing buttons, turning handles, etc.) necessary for the continuity of the narrative/plot/content of the module; control of variables and interference in the final result/product of the module; and/or game.
1.2.2 Contemplative interaction	Contemplation, observation, non-touch visualization/manipulation of an exhibition module or part of it
1.2.3 Reading the panel/text	The interaction occurs by reading the texts aloud (integral or part) on the information boards, panel, caption, text, of the exhibition modules.
2. CONVERSATIONS	
2.1 Conversations about science topics	Dialogues on a scientific topic, discuss ethical and moral dilemmas of science, social impact of scientific activity, bring about data or scientific content, etc.
2.2 Conversations about the exhibition and non-scientific theme	Dialogues on topics covered by the exhibition, but which do not refer to science topics provided in the above category.
2.3 Conversations about exhibition (operation, design, museum experience)	Dialogue prompted by the visitors' interaction with the exhibition and/or the exhibition modules, whether about its operation, design and/or museum experience.
2.4 Conversations that associate previous experiences and personal experiences.	Mobilization, utilization, questioning their own knowledge, beliefs, rituals, ways of life, in the museum experience, making References to childhood experiences, school knowledge; references to movies, books, TV series and shows, etc.

categories (**Table 3**). The option of this research protocol resides in the fact that it dialogues with the socio-cultural perspectives that we refer to in the theoretical framework, which understands learning as a process, with multiple results that includes motivation, interest, conversations and interactions, and that goes beyond the time that visitors stay in the museum. Having in mind that the interactive experience is fundamentally influenced and shaped by interaction and conversation between visitors, the dimensions and categories that constitutes this instrument of analysis are in line with studies that investigate these themes in museums, such as Allen and Gutwill (2016), Ash (2003), Callanan (2012), Rowe (2005), Wagensberg (2005) among others.

In the present article, we utilized an adapted version of this protocol since some categories and subcategories could not be analyzed (for example, visitor-mediator interaction, as the museum did not have these professionals during the data collection) and which respond to our research objective. Thus, we will discuss the results regarding the most expressive dimensions that emerged from the codification of all collected audiovisual material: *Types of Interaction* and *Conversations*.

The segments were coded according to the duration in which the activity and experience took place. The categories and subcategories are not exclusive; the same video clip can be encoded as many times as necessary in a museum experience. For example, *Conversations about science topics* and *Conversations that associate previous experiences and personal experiences* can take place in the same video clip. Aimed at the research participants' anonymity, to transcribe the conversations, we used letters and numbers (C for child and A for adult. Number 1 was applied to the child with the camera, 2 for the second child belonging to the same group, and so on; and sequential numbers for adults in the same group).

RESULTS AND DISCUSSION

The videos of the ten family groups totaled 5 h 58 min 32 s of recording. Based on its analysis with the adapted research protocol, we identified 1,669 occurrences of categories in activity segments related to the visiting experience. **Table 4** shows the dimensions and categories of analysis with their respective occurrences in absolute numbers and percentage in

TABLE 4 | Categories organized by occurrence, time and percentage in relation to total recording time.

Analysis categories and subcategories	Occurrence	Duration (min)	% In relation to the total visit time
1. TYPES OF INTERACTION			
1.1 Visitor- visitor	127	303	84.5%
1.2 Visitor-exhibition module			
1.2.1 Interactive activity	105	137	41%
1.2.2 Contemplative interaction	239	110	30.8%
1.2.3 Reading the panel/text	157	22	6.2%
2. CONVERSATIONS - Content of conversations			
2.1 Conversations about the exhibition (operation, design, museum experience)	514	82	22.9%
2.2 Conversations about science topics	291	67	18.8%
2.3 Conversations about the exhibition and non-scientific themes	170	23	6.4%
2.4 Conversations that associate previous experiences and personal experiences	66	10	2.8%

relation to the total visit time. It is important to note that, when we are looking at how long each category lasts, it is necessary to have in mind that, in this case, no category will last longer than 5 h 58 min 32 s, which is the total duration of the videos. However, the sum of the times of each section can exceed this value, since at different times the categories can overlap. In the description of the results we also present the co-occurrences, which are the occurrences that overlap.

The *Visitor-visitor* relationship, subcategory of *Types of Interaction*, was coded (N = 127) and showed that families interacted with each other 84% of the total visit time, corresponding to a little over 5 h in duration. In the *Visitor-exhibition module* interaction, the subcategories *Interactive activity* (N = 105, 41%) and *Contemplative interaction* (N = 239, 30.8%) indicate a longer time rate, when compared to the subcategory *Reading the panel/text* (N = 157), which was less expressive in relation to the total visit time (6.2%). However, it is observed that in relation to occurrence, it had more applications than the *Interactive activity* category, which can be explained by the type of difference of these interactions: while reading can occur many times, for brief periods of time, the interactive activities can occur for a longer time, as they are characterized by manipulating objects, immersion and other touch and engagement activities.

In the *Conversations* category, the *Conversations about the exhibition (operation, design, museum experience)* and *Conversations about science themes* are the most frequent, with 514 codifications (corresponding to 22.9% of the total recording time) and 291 (18.8% of the time), respectively. *Conversations about the exhibition and non-scientific theme* (N = 170) correspond to 6.4% of the total visit time, applied in recurring episodes of associations between the constellations and the astrological signs. Less frequently, there were *Conversations that associate previous experiences and personal experiences* (N = 66), corresponding to 2.8% of the total time. We found that despite the small expressiveness of the *Conversations that associate previous experiences and personal experiences*, it was very important to facilitate strategies for a shared understanding of new information on the topic of exhibition between families.

In summary, these results indicate that the dynamics of the groups visiting the Museum of the Universe consisted of the interaction between the family members themselves and their interaction with the exhibition most of the time, through interactive activities, moments of contemplation and reading. In this process, the most frequent conversations were about the use and functioning of the exhibition modules, followed by *conversations about science topics*. Both were facilitated by the reading behavior, both to understand how to interact with the exhibition and to expand the subjects covered. This data can be confirmed when co-occurrence takes place, that is, when two or more categories are marked in the same segment. In the analyzed segments, the category *Reading the panel/text* with *Conversations about the exhibition (operation, design, museum experience)* were identified 61 times, and 75 times with *Conversations about science topics*. In the data analysis, the number of times the co-occurrences happened was divided into four levels, namely: 1) Very low: up to 31 times; 2) Low: 32 to 61 times; 3) High: from 62 to 92; and 4) Very high: above 63.

How do Families Interact?

Blud (1990) argues that "the interaction between visitors can be as important as the interaction between the visitor and the exhibition." In relation to this category (*Visitor-visitor*), we note that some families remain together for the entire duration of the visit, while others split into pairs or trios for short periods, but always return to the group to share their observations. These behaviors that highlight differences in family dynamics were also observed in studies developed by Ash (2003), Falk and Dierking (2000), McManus (1992). McManus (1992) compares the families' behavior to groups of "hunter-gatherers" in search of knowledge.

Other behaviors were recurrent in the families' interaction, among them we highlight the behavior of family members that point to identify the exposed objects and/or direct and call attention to show something that, to a greater extent, was observed in the children's behavior. Most of the time, children were the first to show interest by activating the exhibition modules. However, the behavior of parents/caregivers operating the modules was recurrent while the children participated in a more passive and curious way. When children activated a particular interactive device on their own, they usually failed and had to wait for the adults

TABLE 5 | Examples of *Contemplative interaction* and *Interactive activity*

Ex. 1 (G6) C1: [Looking at the setting in the interactive experiments section] *Look dad*./A1: *It's night, right. Wow... the mountains*./C1: *Look how beautiful that blue looks*!/ A1: *Stay*
Ex. 2 (G4) C1: [Looking at the stars painted on the ceiling] *Wow, dad, did you realize there are stars?*/A1: *Look. There is a sky of stars here*/. C1: *That is so cool!!*
Ex. 3 (G5) A1: [All members of the group on the scale to discover their body mass in the sun] *Wow! Do you know how many kilos we would weigh in the sun? The three of us together?*/C2: *No.*/C1: *No.*/A1: [Reading the scale result] "*3180 kg!*"/C2: [Surprised] *Unbelievable!*
Ex. 4 (G3) A1: [When A1 shows C1 the cryogenics capsule] *This is to cool it down. To slow the astronauts' aging.*/C1: [Inside the capsule] *this is to freeze?*/A1: *Over there it is to freeze. To be able to travel many years*

to help and explain. Szechter and Carey (2009), who investigated parent-child interactions in 38 different exhibitions at the Laser Interferometer Gravitational-Wave Observatory (Los Angeles, United States) showed that children are the ones who choose the exhibitions for their families. In this respect, the data presented, in line with the literature, point to interesting relationships between family members with regard to the choice, indicating that children have an important role in family dynamics to direct the learning experiences.

The Museum of the Universe, through its interactive and contemplative exhibitions, provided families both the presence of moments of esthetic appreciation, admiration and observation, as well as interactive activities by handling the devices, with the intention to explore, test ideas and have fun. The *Contemplative interaction* was present in all spaces of the museum, but it was observed to a greater extent in the exhibitions located on the second and third floors, which displayed their information through resources such as textual panels, videos and photographs. On the first floor, this category was observed when families contemplated objects, including representations of the cosmos (Ex. 1 and 2), replicas of spaceships and equipment used by astronauts.

The expressiveness of the *Interactive activity* category was greater on the first floor of the exhibition, supported by the exhibition "Spaceship School". In this space, all families used interactive devices such as scales to discover the visitor's body mass on different planets (Ex. 3); the representation of the cryogenic capsule (Ex. 4); the spaceship's pilot chair, which is an immersive interaction, and modules with touchscreen panels that encouraged families to discover more information about space exploration achievements. The following (**Table 5**) are some representative examples of these categories. The study was carried in Brazil and, therefore, the language was Portuguese. The quotes were translated into English in the scope of this paper; all the quotes are presented in Tables.

In the examples presented in **Table 5** and at other periods of the visit, we found that the exhibitions are the starting point for family conversations. However, this result should be viewed with caution because the absence of conversation can have different meanings, for example, they can mean lack of engagement and/or it can also mean moments of contemplation (Leinhardt, 2014). In examples 1 and 2, families verbalize their contemplation of the exhibition when C1 of G4 looks at the ceiling painted with stars for a few moments and then remarks to the father "Wow, dad, did you see the stars?" However, most of the codes applied in the category *Contemplative interaction*, were observable through the behaviors explained in the videos by non-verbal and/or corporal expressions.

The *Interactive activities* also provided moments of leisure and family relaxation, as seen in example 3, where all members of the group step on the scale to see what the family's body mass would be in the Sun, as well as important for conversations that addressed an idea, knowledge or curiosity about science, for example, when the father shows the cryogenics capsule to the child (Ex. 4).

Also in relation to the families' interaction with the exhibition, it was found that because the museum is widely marked with texts and panels, it favored the presence of the *Reading the panel/text* category and mobilized the families to interact. In general, the textual resources displayed in the exhibitions were not long and/or complex, which allowed families to read quickly, to understand, for example, the how a specific device functions or to situate themselves on what is being observed and/or exposed–interaction that stands out later in 3.2 What do families visiting the Museum of the Universe talk about? The reading was usually done by the parents/caregivers and occasionally by the children, since the children's age group in the study comprised preschoolers up to 4th grade elementary school children, as observed in the following examples (**Table 6**).

As can be seen in examples 5 and 6, the parents/caregivers did the readings using the panels to talk to the children about scientific concepts and curiosities of the exposed objects, while the children also offered their interpretation of what was read, as for instance the G7 in which the child utters "I won't go in there" when the adult read that the cryogenics capsule cools the temperature of the human body to -120°. According to Crowley and Jacobs (2002), this reading behavior is fundamentally collaborative–the parents read the text, answer the children's questions, ask their own questions and point out interesting parts that are reflected in the text. Tare et al. (2011) also indicate that the parents/caregivers do the reading and, depending on the complexity of the subject, adapt it to explain it to the children.

However, children's readings, for adults and for themselves, were brief and more focused, with no continuity about what they read (Ex. 7 and 8), which may reflect their schooling phase and literacy, as well as general age behavior that results in fragmented focus when the environment has multiple visual and interactive inputs. These data are in line with research that investigated the learning behaviors of families in science museums, which

TABLE 6 | Examples of *Reading the panel/text*.

Ex.5 (G6) A2: [Reading the text from the monitor to C1] "*Our body has an internal clock. It is possible to measure time by counting the heartbeat. Count the pulse beats during the oscillation.*"
Ex.6 (G7) A1: [Reading to C1 about the cryogenics capsule] "*To delay the astronauts' aging, the cryogenic capsules cool the human body to a temperature of -120°"/C1: I'm not going in there.*"
Ex.7 (G4) C1: [Reading the panel] "*Crown, photosphere, chromosphere, convective layer and nucleus.*"
Ex.8 (G2) C2: [Reading the panel] "*Earth's crust formed four billion years ago*" [talking to C1 and pointing to the panel] *Look over there [...]*/C1: *I saw it*

dissipate a view that visitors do not read (Allen, 2002; Tare et al., 2011).

What do the Families Who Visit Museum of the Universe Talk About?

Regarding the experience of visiting the Museum of the Universe, the analysis indicates that overall, the families talked about the exhibition, its operation and contents. Regarding the conversations about the exhibition, we highlight the dialogues where the parents/caregivers explained to the children how the exhibition modules worked (*Conversations about the exhibition–operation, design, museum experience*). The following are examples (**Table 7**) from this category, highlighting Example 9, which occurs in the expository module "The Earth in Movement", which, among other issues, addresses how tides are formed. In this interaction, the adult explains to the child how the Moon moves using the touchscreen.

Interactive exhibitions, such as those at the Museum of the Universe, can elicit productive conversations because they are able to show and represent complex and abstract phenomena in action (Tscholl and Lindgren, 2016). The expectation is that, when interacting with the devices, families not only talk about how it works ("press a button", "lift a handle" etc.), but also discuss beyond what is immediately observable, including discussing ideas, logical reasoning and/or underlying scientific knowledge.

However, our study indicated there were few *Conversations about science topics* that resulted from the *Interactive activity*. About this, Gutwill and Allen (2010) argue there is generally insufficient alternative hands-on interactive exhibitions to stimulate prolonged and personalized involvement in order to keep children and parents/caregivers interested in exploring and talking about a phenomenon. Even so, we recognize that the *Conversations about the exhibition* (*operation, design, museum experience*) presented important structures for understanding the families' learning experiences, viewed as scaffolding for the construction of collective knowledge about astronomy.

In the category *Conversations about science topics*, we verified how the families in this study approached and/or appropriated scientific terms, concepts, ideas and procedures, and we also identified the contribution of the exhibitions in dialogues that included questions related to the nature of science. Ash (2003) states that the conversations show how families use the content of an exhibition as a springboard for extended reasoning. Thus, we present below some examples of these conversations (**Table 8**).

The episodes presented above indicate that the parents/caregivers, in addition to reading the texts, asked questions and provided explanations about astronomy to guide their children's understanding during the conversations throughout the visit, in some cases also correlating it with the *Interactive activity*, such as in example 12. Adults stimulated the children's skills such as identification, naming and comparison, asking concrete questions in order to keep the children involved, for example, when in G3 A1 asks C1: "what planet is that little one there? Do you know?" or in G2, when A1 asks the children (C1 and C2): "Did you track the order (of the planets)?" Skills such as inference, logical reasoning, comparison, abstraction and generalization were also observed in scenes like in example 12, in the interaction with the body mass scale on the different planets (Ex. 13). In general, families also made associations and personal connections with scientific knowledge to facilitate understanding the topics exposed (Ex. 14, 15, and 16), and established initial conclusions after observation, reading and analysis (Ex. 13).

Research has shown that as conversational partners, parents/caregivers can focus their attention, provide explanation and interpretation, and organize display material to support children's learning (Leinhardt et al., 2002; Crowley et al., 2014). These studies indicate that explanations provided by

TABLE 7 | Examples of *Conversations about the exhibition (operation, design, museum experience)*.

Ex.9 (G1) A1: [Reading the text in the "earth in movement" module to C1] "*Tides are produced by the attraction of the Moon and the Sun over the ocean waters. Touch and move the moon to see the tide rise and fall." Look, daughter! [...] when you touch the moon"* [moving the moon with his finger on the touchscreen] *"the tide goes down* [moves the moon in the opposite direction] *and here it goes up. See?*
Ex.10 (G4) A1: [In the interactive module with astronomical information] *I still don't understand this thing here*./C1: [Going in the direction of A1] *where is it?*/A2: [Going in the direction of A1] *Let me see/*. A1: [When the other two visitors approach] *What is it supposed to do?*/C1: *OK, I got it now. Cool!*/A2: *Hum, he (the character) will find out where he is. Finding a sextant and a watch. But I don't know if he's looking for that now.*/A1: *But what is he supposed to do?*/C1: [Starts playing by moving the character] *Like this. He has to find the watch.*/A2: [...]*This one is complicated, huh*
Ex.11 (G7) A1: [in the interactive experiments section] *Look,* [reading the module text] *the "Configuration of the Planets. You know that the planets traverse the constellations of the zodiac as they move around the Sun ..."*/C1: [Interrupting] *let's go see other awesome things*

TABLE 8 | Examples of *Conversations about science topics*.

Ex.12 (G4) A1: [Talking to C1 in the interactive module with scales to see their body mass on different planets] *Come and see what your weight is on Pluto. Stay here in the middle of the scale to see.* [Looking at the scale display] *On Pluto you only weigh 1.3 kg/*C1: [Impressed with the result] *What?!/*C2: [Stepping on the scale] *I also want to see./*C1: [Referring to C2] *You must weigh some grams./*A1: [Looking again at the scale display] *Less than a kilo. 0.9 kg./*C1: [Moving the model that demonstrates the layers of pluto] *Here, folks, it's inside Pluto. Really cool.* [Pointing to the core]. *Dad, what is this ball for?/*A2: *These are the layers inside the planet*. [...] *this layer here is the crust*./C1: [Referring to the core] *And this one controls everything?/*A2: *No. this one is the crust, it has an ice sheet and here is a solid rocky core* [pointing to the text] *It's written here. "It's the structure of Pluto."*
Ex.13 (G7) A1: [Reading the panel to C1] *Look at this, "one rotation of the Sun corresponds to 26.8 days on Earth." Did you understand what that is?/C1: [uncertain] Yes .../A1: It takes 26 days for the Earth to move around the Sun*
Ex.14 (G1) A2: [Watching the video of men on the moon] *Look, daughter, they over there on the moon.* [Imitating the astronauts' movements] *They have to walk like this, because there is no pressure for them to stay on the floor.* [Pointing to the video] *They walk like that, leaping./*C1: *But why, dad?* [Imitating a person walking normally] *why don't they walk like this?/*A1: *Because there is no atmospheric pressure, daughter*
Ex.15 (G3) A1: [Pointing to the solar system model] [...] *Look at the planets, the Sun ... what planet is that little one there? Do you know?/C1: Yes. It's Mercury./A1: And then?/C1: Venus./A1: [...] and then?/C1: Earth ./A1: [...] and then?/C1: Mars./*A1: [Pointing to jupiter] *And this one here?/*C1: *Jupiter!/*A1: *Wow!* [pointing to jupiter] *And this one here?/*C1: *Saturn/*A1: *That's right.* [Pointing to uranus] *And that one over there?/*C1*: Uranus!/*A1: *And the last one?/*C1: *Neptune!/*A1: *Very good!/*C1: *Daddy, where's Jupiter's rings?/*A1: [...]*but does Jupiter have a ring?/*C1: *Yes./*A1: *Oh, but it's very thin. You can't see it, right.* [...]*Did you see how big the sun is? The Earth is tiny there. Mercury is tiny, right?/*C1: *É. [...] Yes. [...] And where's Neptune's rings?/*A1: [Looking at the representation uranus and rings] *Hey, isn't that one over there? No, that one is Uranus, right?/C1: Yeah. What about Neptune?/*A1: *Neptune also has a ring, right? We saw it the other day. When they did that, I think they didn't even know that Neptune had a ring. Or it is because Neptune's ring is also very tiny?* [Pointing to saturn] *The one with the most ring is Saturn.* [When A2 joins the group] *Do you want to teach mom the names of the planets?*
Ex.16 (G2) A1: [Talking to C1 and C2] *Did you memorize the order (of the planets)? I'lll teach you a trick and you will never forget the order: "My Old woman Bring My Dinner, soup, grape, turnip and bread. There is no more bread, right ... Mine is mercury, Old* [in Portuguese, velho] *is venus, Bring* [in Portuguese, traga] *is Earth* [in Portuguese, Terra], *Mine is Mars, Dinner* [*in portuguese, jantar*) *is jupiter, soup is saturn, Grape* [in Portuguese, uva] *is uranus and Turnip* [in Portuguese, nabo] *is neptune". Now you will always know the order [...]/*C2: *What about bread?/*A1: *Bread (Pluto) is no longer a planet.*

adults, even when brief and informal (called "explanatoids"), as noted in examples 13: "A1: It takes 26 days for Earth to go around the Sun" and 16: "A1: Pluto is no longer a planet", can help children process the exhibition material, serve for the initial understanding of scientific concepts and foster subsequent skills (Fender and Crowley, 2007; Tenebaum et al., 2010). These results suggest that the strategies used by parents/caregivers to talk about science with children can facilitate the construction of meaning, promote reflection and/or change what they understand about science.

The data on *Conversations about science topics* also provide evidence that the exhibition "A giant leap: the journey to the Moon," located on the second floor of the museum, provided dialogues that contributed to issues related to the history of science. In other spaces, although less frequently, reference was also made to researchers involved in the process of producing science (Ex. 17 and 18) and the identification of equipment and instruments in the scientific field used by scientists (Ex. 18) in **Table 9**.

The examples presented above are representative of an approximation of families to the idea of science, especially astronomy and astronautics, as a human, historical and social process (Lederman, 2006). As an example, the G4 family (Ex.17) had a dialogue on how science was built in relation to the space race in the second half of the 20th century between the Union of Soviet Socialist Republics and the United States of America for supremacy in the space exploration and technology. In this conversation, family members comment, citing the names of the first astronauts who reached the Moon and use personal experience information ("Your grandmother was ten years old") to make sense of the conversation. The strategy used by this family leads to the discussion of another category that was less expressive in this study–*Conversations that associated previous experiences and personal experiences*–but that demonstrated relevance to the analyzed families' learning experiences. As strategies to facilitate and approximate the exposed theme, some dialogues, albeit brief, mention music and films, children's school content and families' personal experiences (**Table 10**).

Conversations that involve associations and comparisons with past events and previous individual experiences, as in examples 19 to 22, which reinforce family history and shared understanding among family members (Zimmerman et al., 2010). Allen (2002) defines this type of strategy as "connecting

TABLE 9 | Examples of *Conversations about science topics*.

Ex.17 (G4) A2: [Looking at the panel about man's journey to the moon with C1] *Let me tell you. Come on, look how cool this is. The first spaceship launched was Mercury 7. Then years later this guy here, President Kennedy, said that man would be on the Moon by the end of 1969./*C1: *OK, got it./*A2: *Then they tested it. They made the Gemini 3 rocket and then launched this astronaut here, Virgil Grisson and John Young. Then they did the first spacewalk, that is, they left the ship and managed to wonder outside the ship. Then they completed, "what beauty," then he goes back to Earth. Then in 1966, his grandmother was ten years old./*C1: *Wow!/*A2: [...]*they landed a probe on the Moon, without people./C1: Is it still there on the Moon?/A2: It should be. In 1967, Apollo 1 caught fire.* [Pointing to a picture on the panel] *These guys died./*C1: *Oh no/A2: Yeah. Then they made a flight around the Moon and returned to Earth, they did not land. It was these guys here, (from) Apollo 8, James Lovell, William Anders and Frank Borman. Then, on July 21, 1969 they landed on the Moon and this guy was the first guy to walk on the Moon, Neil Armstrong, later it was Buzz Aldrin ./*C1*: Wow! That's so cool*
Ex.18 (G5) A1: [Showing children the panel and the miniatures in the area with interactive devices–1st floor] *"Here, daughter, look ... the first telescope, Galileo did it . . . Galileo Galilei aimed the telescope at the sky and observed wonders never before imagined. His discoveries sparked a revolution in understanding"* [...].

TABLE 10 | Examples of *Conversations that associated previous experiences and personal experiences*.

Ex.19 (G1) A2: [Positions himself as if he is working on the spaceship's controls] *It's Captain Kirk's ship* [referring to the star trek movie]
Ex.20 (G1) A2: [Talking to A1 and pointing to the satellite model] *What's the name of that one over there?*/A1*: What?*/A2: [Remembering the name] *Satellite!*/C1: *Satellite? I never studied what is a satellite*/A2: *Never studied about it?*/C1: *No*
Ex.21 (G4) A1: *You know that on your birthday [...]. your 8 year-old birthday, marked 50 years since mankind first stepped on the Moon.*/C1: *Wow! I'm honored!*
Ex.22 (G5) *Do you remember that Aunt Dri went to Japan?*/C1: *Yes*./A1: *So, Aunt Dri went to Japan and when the sun was up in Japan the sun was down here in Brazil*./C1: *Then when the Sun came here, there was no sun in Japan*

conversations" and adds that they are relevant to make sense of the content of the exhibition. In addition, Callanan et al. (2017) and Jant et al. (2014) point out that the parents' connection with previous experiences in conversations with their children is positively associated with the children's scientific understanding. In this regard, the personal, social and cultural background of the families is mixed with the contents of the exhibition, favoring the learning experiences in science.

Final Remarks

In the present study, our objective was to understand the families' interactions and learning experiences during a visit to a science museum with astronomical content, with a focus on conversational content and interactions. By observing the aspects mentioned in this study, we understand that, during the visit to the exhibitions of the Museum of the Universe, the families demonstrate to be very motivated, interested and focused on the experiences provided, such as the interactive, immersive and contemplative activities.

The interactions and conversations bring evidence that families use the exhibitions as resources to make observations and comparisons, and also serve as a source for sharing knowledge about astronomy among family members. In addition, they use their cultural knowledge and daily activities to contextualize and facilitate understanding a more complex subject that was addressed, in order to comprehend the exhibition. The exhibitions also provide historical contexts so that, to some extent, families are brought closer to the nature of science. The data also show that parents/caregivers played an important role in maximizing the learning opportunities available, offering support and guidance, encouraging questions and providing explanations as the children interacted with the exhibits in order to introduce or improve science knowledge, strategies that were observed in different episodes.

Thus, this study brings evidence that the Museum of the Universe was a platform for families to share experiences, talk and develop, often for the first time, specific ideas, knowledge and concepts about astronomy, enriching the group members' knowledge. In addition, it signals that the experience of the visit can offer subsequent opportunities to broaden and expand the family conversation concerning the topic.

In summary, our study confirms data from the previously mentioned studies, in reference to how families are interacting, the role of parents/caregivers in children's learning, and how reading is an important resource for deepening science topics. We emphasize that, in the Brazilian context, children play an important role in the dynamics of family orientation during visits and, therefore, we consider important that science museums favor their participation in a significant way, with attractive design and easy-to-read texts for who just learned our to read and, when possible, linked to daily life, providing greater autonomy in dialogues with their parents/caregivers. Collaborative exhibits, in which families get involved for a longer time in discussions that value not only the cognitive but the social domain, also show themselves as potential to stimulate deeper conversations in science that are, to a lesser extent, observed in these spaces.

We hope that our study can contribute to theoretical perspectives that will help to better understand the processes about Latin Americans families' learning conversations in informal education spaces. In addition, the study of conversations and interactions through the adopted protocol contributes to provide the educational sectors of the museum institutions to understand the needs, interests and identities of visiting families, in order to stimulate the cognitive and social learning experiences.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by this study was approved by the Ethics Committee of the Oswaldo Cruz Foundation (CAAE 10663419.0.0000.5241). All participants consented to their participation through the free and informed consent term, which had information about the research procedures and objectives. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

Equal contribuition & Senior autorship – LM. Equal contribuition – JR and GS. Equal contribuition and Last autorship – YS, WC, and LG.

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Using Individualized Photobooks to Enhance 3- and 4-Year-Old Children's Science Identity Through a Science Outreach Program

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This paper describes how individualized photobooks were used to support 3- and 4-year-old children in demonstrating their science learning and developing their science identity through participation in a science outreach program. Photographic images stimulate children's visual thinking and allow them to provide explanations of complex concepts using their language, thus supporting children at their level of understanding. Twenty child/parent dyads were video-recorded interacting with the exhibits during a Science Outreach program into Western Australian community playgroups. Screen shots from the video-recordings were used to develop individual printed photobooks for each child. One week after the program, the photobooks were used in a photo-elicitation conversation with the children (accompanied by their parents) about how the exhibits worked. Children took their photobooks home and 7 weeks after the program parents were interviewed about how the photobooks were used. The photobooks were found to assist the children in demonstrating their science understandings by providing a context for conversation and allowing the children to show their competence, use multiple forms of communication (verbal, non-verbal and through parent), and participate or withdraw on their terms. At home, the photobooks were found to be a focus for the children to share their knowledge of the Outreach program with family members, give the children a voice, and provide them with time to express their understandings. Having the child as narrator of his/her story and the adult as listener empowered the child's sense of identity. The use of individualized photobooks was found to contribute to the development of the children's identity and increase their agency in science and enhanced the parents' perceptions of their children as young scientists.

Keywords: visual methodology, photo-elicitation, individualised photobooks, young children, science outreach program, science identity

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INTRODUCTION

Science is the domain of the young as they strive to make sense of their world. The wonder and curiosity that motivate young children to play, explore, observe and question assist them to develop their own explanations and understandings of the world (Campbell and Howitt, 2021). Positive and developmentally appropriate science learning experiences in the early years can assist in developing "young children's scientific concepts, awareness of scientific explanations through engagement with science phenomena, science process skills, use of scientifically informed language, scientific thinking skills and positive attitudes to science" (Howitt et al., 2017, p. 209). These, potentially, can contribute to a young child's sense of science identity.

As discussed by Fenichel and Schweingruber (2010) in relation to informal contexts, science identity refers to how one perceives that he or she can do science and be successful at science, and how others perceive him or her being able to do science. Developing an understanding of science and a science identity is influenced by social interactions with others and science resources available within learning communities (Kim, 2018). Recognition of belonging to a science community, whether reflecting on past science events, engaging in current science activities, or imagining future science scenarios, can assist the development of science identity (Fenichel and Schweingruber, 2010). Family is the predominant social group to influence participation in, and learning of, science, with everyday parent–child interactions having the potential to influence science identity in young children through the interests, habits, and scientific thinking that can be developed (Crowley and Galco, 2001; Katz, 2011). This research explores how science identity can be fostered in young children through individualised photobooks that recorded children's engagement in a science outreach program. The next section provides an overview of learning in informal contexts and the impact of outreach programs, followed by a description of visual methodologies for data collection, photo-elicitation and the creation of the photobooks.

Science learning that occurs outside of formal educational settings has been labelled 'out-of-school learning,' 'informal learning' or 'learning in informal contexts.' These environments could include science centres, museums, zoos, botanical gardens and family settings. Learning in such environments is characterised as voluntary and free choice as children chose where to direct their attention, which, in turn, can influence their motivation and interest in learning (Dierking et al., 2003; Rennie, 2007). This choice accommodates children's different interests, "offering unique opportunities to engage in experiential learning" (Riedinger, 2012, p. 126). Stocklmayer et al. (2010) noted that the use of the affective domain to promote engagement, along with activities that not only engage children to learn about science but also do science, is essential to enhancing learning in informal contexts.

Many science centers seek to serve their community through the provision of outreach programs, such as taking interactive science exhibits into community settings. These programs can provide attractive opportunities to engage both adults and children in science. Research has demonstrated that the potential to learn from exhibits in community-based science outreach programs depends on the availability of people who can encourage or guide children's exploration of the exhibits (Rennie et al., 2010). This outcome is consistent with findings from research in museums; that greater learning has been found to occur when exhibits encourage social interaction and collaboration among family members (Puchner et al., 2001; Meisner et al., 2007), highlighting the socio-cultural underpinnings to learning within informal learning contexts (Rennie et al., 2003). For young children in particular, research with exhibits has pointed to the importance of family talk and guidance in science learning (Ash, 2003; Knutson and Crowley, 2010; Dooley and Welch, 2014). As Schwan et al. (2014) concluded, "conversations between child and parents [can lead] to a co-construction of science-related meaning" (p. 73). Similarly, findings from a synthesis of research on children's learning in a range of informal learning environments emphasised the importance of scaffolding (Andre et al., 2017).

It is not surprising, then, that a detailed study by Howitt et al. (2017) concluded that science outreach programs aimed at young children should provide emotional support to encourage children's exploration of the exhibits, incorporate modelling to demonstrate how exhibits work, and use open-ended questions to extend children's thinking. Further, outreach staff should assist adult carers to understand and acknowledge the place of play and learning as complementary; encourage active adult engagement with the children and the exhibits; and acknowledge children as capable and competent science thinkers, learners and communicators. How such science outreach programs can assist young children to develop their science identity was explored using photobooks as a visual method to investigate the science-related outcomes of participation.

The term 'visual methodologies' refers to the collection of methods used to understand and interpret images, including photographs and videos, that have emerged from anthropology and sociology (Glaw et al., 2017). The affordances of visual methods have been highlighted in research with children: capitalising on children's multimodal meaning making, positioning children as capable communicators, acknowledging children as experts in their own lives, providing children with a voice, building understanding of children's lived experiences, positioning children as co-researchers, and upholding children's rights (Clark, 2011; Heydon et al., 2016; Rose, 2016). The use of visual methods encourages a postmodern perspective of childhood, where children are considered "knowledgeable, competent and powerful members of society" (Einarsdottir, 2006, p. 525).

Photo-elicitation is a visual method in which photographs are used during interviews to prompt responses from participants (Meo, 2010). There are many variations in how the images can be used: photographs taken and assembled by adults (Smith et al., 2005), photographs taken and assembled by children (Einarsdottir, 2005), or a combination of these approaches (Pyle, 2013). Photographs have been found to be an effective way of locating a conversation in children's experiences because they provide a focus and context for the interview (Stephenson, 2009) and allow children to communicate through visual and verbal means (Clark, 2011). Due to their ability to evoke feelings and memories, photographs can produce more and different kinds of information and responses to those obtained through conventional interviews (Harper, 2002).

Photographs have been found to enhance children's comfort level, engagement, and position within the research process. With attention placed on the images rather than themselves, children can express their ideas and feelings more freely (McIntosh and Stephens, 2012). Images produced by children or of children and their contexts enhance engagement due to familiarity (Pyle, 2013). As both the researcher and participant have some knowledge of the images, photo-elicitation becomes a collaborative effort to develop shared understanding where children are involved in both data collection and data interpretation (Glaw et al., 2017). Further, when children can take the lead in describing the photographs and may enter and leave the photo-elicitation session as they chose, the power relationship between researcher and child can be shifted (Epstein et al., 2006).

Pyle (2013) used photo-elicitation to obtain the perspectives of 32 children aged 4 and 5 years on their classroom-based learning experiences. Both children and the researcher took photographs, which were discussed across three photo-elicitation sessions. The affordances of the photo-elicitation technique were found to relate to the children's competence and ability to actively guide the process, appropriate contextualisation with the photographs which led to insightful comments from the children, and the use of children's verbal and non-verbal communication in analysing the photographs.

Creating a photobook involves selecting, annotating and organising photographs so they are presented and bound as a book, giving them permanence and importance. Katz (2011) investigated how a printed photobook designed around a 6-year-old boy's exploration of the world impacted his identity as a scientist. The 20-page book contained chronological photographs of the boy participating in science activities, each captioned with an open-ended question relating to science. Photo-elicitation was then used to establish the boy's perceptions of what he was doing, what he was learning, and what science was. The findings highlighted that repeated reading of the photobook supported both the boy's vision of himself, and the adults' vision of him, as a scientist. Through ongoing conversations around the photobook, "adult attention and childhood experiences" were brought together to "create a socio-cultural environment conducive to learning science" (Katz, 2011, p. 534).

Photographs have much potential to encourage children to explain complex science concepts using their language, and to support their visual thinking and understanding. The research in this paper is guided by the following question: How does the use of individualised photobooks support 3- and 4-year-old children in demonstrating their science learning and developing their science identity through participation in a science outreach program?

MATERIALS AND METHODS

Context

This research was part of a larger project that aimed to understand and find ways of improving parents' and young children's interest and engagement in science through their participation in an Australian science center's Early Childhood Outreach program. This program (subsequently referred to as the Outreach program) delivered a set of science-related interactive exhibits into community playgroups. Playgroups are weekly community events where parents and their young children meet to interact in a wider social environment with a focus on play. Findings relating to young children's interactions with the Outreach exhibits are presented in Rennie and Howitt (2020). This paper presents information relating to the use of photobooks to enhance young children's science identity.

The Outreach program was designed for children up to 4 years of age. Designed around free play and guided play, the hour-long program encourages children to use their senses to better understand the world through a range of hands-on exhibits. One of two presenters introduced the program to the children and their parents, using a puppet to focus the children's attention on their senses of hearing, sight, smell, and touch. Children then have 30-40 min of play with 11 exhibits that include investigating moving objects with magnets, creating sounds, identifying smells, exploring how air can move objects, testing floating and sinking, exploring cogs and ramps, and observing the characteristics of living things. The presenters are available to interact with the children and encourage parents' participation to support their children's learning as they engage with the exhibits. The program concludes with the children gathered to hear a story related to the senses.

Research Design

A multiple case study research design was used in this research. Case studies provide an holistic means of describing and interpreting phenomena in context, providing an in-depth understanding of those phenomena (Merriam and Tisdell, 2015). The phenomena of interest here were how individualized photobooks, developed from video-recordings of children and their parents interacting with the exhibits in the science Outreach program, assisted the children to demonstrate their science understanding and how the photobooks were later used at home. Within this research, the child/parent dyad was considered the case as children and parents tended (and were encouraged) to interact with the exhibits together. The multiple case design allowed common themes across the individual cases to be identified and described in a cross-case analysis.

Data Collection

Data were collected during the Outreach program's visit to five playgroups (four metropolitan and one regional) across an 18 months period. Approval for the research was obtained from an institutional human research ethics committee, the playgroup, and the parents involved. One week before the intended visit by the Outreach program, the researchers attended each playgroup to provide parents with an information booklet about the research and it was described to them verbally. Parents were invited to ask any questions and encouraged to discuss the research with family members before agreeing to participate. Children also had the research described to them through watching and discussing a digital story (Mayne et al., 2017).

A shown in **Table 1**, data collection consisted of video-recording child/parent dyads interacting with the exhibits, preparation of the photobooks, photo-elicitation sessions and interviews with parents. In these playgroups, all of the parents were mothers. Each of these aspects are described below.

TABLE 1 | Summary of data collection.

Timeline	Activities relating to data collection
During program	Video-recording of child/parent dyads interacting with exhibits
2–5 days after program	Preparation of photobooks from video stills
1–2 weeks after program	Photo-elicitation with child/parent dyads to determine how the photobooks assisted children in demonstrating their science understanding (*n* = 20, 11 boys and 9 girls). Photobooks taken home
7 weeks after program	Interview with parents (n = 15) to determine how the photobooks were used at home. (Five parents not available)

FIGURE 1 | A sequence of photograps showing a child and parent interacting with plastic insects.

Video-Recording of Child/Parent Dyads

At least two researchers attended each playgroup during the Outreach program for observation and video-recording the interactions of those children whose parents had given their permission to be involved in the research. Video-recordings were made using tablets, which were selected due to their portability and unobtrusive nature, as opposed to a video camera mounted on a tripod. Also, due the pragmatics of a playgroup setting, where young children move freely around a room crowded with science exhibits, a standing tripod was considered unsafe. The portability of the tablet allowed the researchers to follow specific child/parent dyads to individual exhibits and record detailed interactions between the child and parent with the exhibit. Additionally, the tablets were held at chest height to record interactions, reducing any possible anxiety associated with holding a camera at eye level (Flewitt, 2006).

Short (ranging from 8 s to 7 min) video-recordings were captured of the child, and where possible the parent, interacting with the various exhibits. These video-recordings attempted to capture an entire sequence from the start of the interaction with an exhibit, any discussion or problem solving occurring between parent and child, through to the completion of the activity or until the child walked away. Most children in the playgroup moved between the different exhibits according to what interested them, although they were sometimes guided by their parents. In this manner, the children could come back to an exhibit several times. The number of video-recordings made for the child/parent dyads ranged from 4 to 13.

Preparation of Photobooks

The week following the Outreach program, individual printed photobooks were prepared for each child/parent dyad to provide a summary of their interaction with the science exhibits. Each video was observed by the researcher who made it, and screen shots were taken to capture actions that characterised children's interactions with the exhibit. Using screen shots from the video allowed the researchers to select only those images that had the participating children and/or parents in them. This overcame one of the ethical limitations attached to using photographs in research; that is, children whose parents had not given permission for them to be recorded were excluded (Pyle, 2013). Up to four screen shots were obtained from the video for each exhibit in order to highlight a sequence of events. For example, one sequence of three photographs was a child placing a feather in a bottle, squeezing the bottle, and watching the feather fly out. Another example was a sequence of four photographs of a child and parent interacting with plastic insects. **Figures 1A–C** show three of these photographs, with the fourth photograph not presented as it shows the participants' faces. In the first photograph (**Figure 1A**), the child and parent are using magnifying glasses to explore the insects. The second photograph in the sequence, which is missing, shows the child pointing to a plastic ant. The third photograph (**Figure 1B**) shows the parent holding a plastic fly and the child pointing to it. The fourth photograph in the sequence (**Figure 1C**) shows the child tapping his shoulders as if to indicate where his wings might be.

Photographs were printed in full color as either A4, A5 or A6 size and placed into plastic sleeves of a folder. Each book had the child's name on the cover and the pages numbered. There were no words in the book. Photobooks of children engaging with the exhibits ranged from seven pages with 10 photographs to 16 pages with 27 photographs. The number of exhibits in the photobooks varied from one to eight.

The Photo Elicitation Process

This photobook was used as the basis for the photo-elicitation conversation with children and parents at the next visit to the playgroup. All conversations with the children were conducted by the first author and audio-recorded. They occurred in a separate place to the main playgroup, at a time when both child and parent

TABLE 2 | Description of child/parent dyads in photo-elicitation process.

Dyad number*	Child's age	Child's gender	Child's confidence during photo-elicitation conversation	Number of different exhibits in photobook	Length of conversation (min:s)	Parent interviewed at 7 weeks
Dyad 1.1	3 years 6 months	M	Confident	7	6:20	Yes
Dyad 1.2	3 years 7 months	M	Quiet	2	8:02	Yes
Dyad 1.3	3 years 5 months	F	Confident	6	8:34	Yes
Dyad 1.4	3 years 9 months	F	Did not engage	4	6:09	Yes
Dyad 1.5	3 years 3 months	M	Confident	5	4:12	No
Dyad 2.1	4 years 6 months	M	Confident	7	12:33	Yes
Dyad 2.2	4 years 4 months	M	Quiet	7	13:11	Yes
Dyad 2.3	4 years 4 months	F	Quietly confident	6	8:17	No
Dyad 2.4	4 years 4 months	M	Confident	7	13:40	No
Dyad 3.1	4 years 0 months	F	Confident	8	11:06	Yes
Dyad 3.2	3 years 11 months	M	Quiet	1	6:44	Yes
Dyad 3.3	3 years 11 months	M	Confident	8	9:16	Yes
Dyad 3.4	3 years 2 months	M	Quietly confident	8	9:38	No
Dyad 4.1	3 years 2 months	F	Quiet	7	13:59	Yes
Dyad 4.2	3 years 4 months	F	Confident	6	9:51	Yes
Dyad 4.3	3 years 2 months	F	Quiet	7	8:46	Yes
Dyad 5.1	3 years 7 months	F	Quietly confident	7	9:56	Yes
Dyad 5.2	3 years 11 months	M	Confident	6	9:00	Yes
Dyad 5.3	3 years 6 months	M	Confident	8	11:41	Yes
Dyad 5.4	3 years 7 months	F	Confident	8	12:40	No

were ready to engage. The children were asked to descrsibe who was in the photograph, what they were doing in the photograph, and how the exhibit in the photograph worked. The children used a wide range of non-verbal communication, such as pointing, turning the page, gross motor actions such as pumping, and showing affective responses such as laughing. These were described verbally by the researcher for the benefit of the audio recording. The children were told that if they did not know the answer that was okay. Notably, the children were also asked "Would you like to turn the page?" to check their ongoing willingness to participate.

The child's parent was always in attendance, usually encouraged their child, and often was also a participant in the conversation. These conversations were guided by the children's ability to converse and their interest in the photobook. When children said they did not wish to turn the page, or walked away from the photobook, the conversation ended. Conversations lasted between 4 and 14 min. At the end of the conversation the children were presented with their photobooks to take home.

All conversations were fully transcribed by the first author who had conducted them to capitalize on her familiarity with the children's language and context. This transcription included copies of the images from the children's photobook. The children's observed confidence during these conversations was recorded as confident (spoke freely), quiet (provided short answers through parent) or quietly confident (spoke freely but with some assistance from parent).

Seven weeks after the program a final visit was paid to the playgroup to interview those parents who attended. Parents were asked if their child had shared the photobook with anyone and how it had been used at home. These audio-recorded interviews lasted from 5 to 10 min and were later transcribed.

At all times while attending the playgroups, the researchers demonstrated a listening and respectful approach to both children and parents. This was reflected in a flexible and welcoming approach to data collection that invited the children to look at their individual photobooks. It also included close observation of the children's body language to check for engagement with the process. An example of this was children looking and pointing at the book, rather than looking away.

Table 2 provides an overview of the children and their parents who were involved in the photo-elicitation process. A total of 20 children and their parents took part in both the video-recordings and photo-elicitation conversations, while 15 of these mothers/carers were available for the parent interview 7 weeks after the program. Only one child chose not to engage with the photobooks at the 1-week conversation (Dyad 1.4—refers to Playgroup one, child/parent four), and so her data has not been included in analysing the photobooks. However, her mother did provide information at the 7-weeks interview and this data has been included. One grandmother attending as carer was interviewed in lieu of the mother at the 7-weeks interview (Dyad 4.2).

Data Analysis

Children's transcripts were read and interpreted in the context of the photographs taken from the video-recordings. Children were classified as knowing what they did if they correctly described their actions at 50% or more of the exhibits in which they engaged. Similarly, children were classified as understanding how the exhibits worked if they correctly explained or modeled the working of 50% or more of the exhibits. Some children were initially shy and did not answer, but then warmed up to the task and provided explanations, and these were also classified as understanding.

Data analysis was conducted using an inductive approach through thematic analysis (Merriam and Tisdell, 2015). All photobook analyses were completed by the first author who was familiar with each child through conducting and transcribing the conversations. Three rounds of coding were used to identify the themes relating to how the photobooks assisted the children in demonstrating their understanding of how the science exhibits worked. Initially, a description of each child was written that summarized how the photographs provided a context, the forms of communication being utilised by the child, and what the child understood, along with identifying relevant examples. This process was mostly driven by the data itself, although the literature did inform initial themes. The second round of coding further described the emerging themes of context, competence, and communication for each child, while adding the theme of participation. The final round of coding related to the cross-case analysis and how the themes were distributed across the children. The original video-recordings of the children's interactions with the exhibits and audio-recordings from the conversations were referenced to clarify any aspects.

To determine how the photobooks had been used over time, the parents' 7-weeks interview transcripts were read. The first author developed the initial themes, which were then discussed with the second author. After two rounds of coding, parents' comments were categorised in relation to how the child had shared the photobook, cognitive aspects (the child had used the photobooks to talk about what they did, the child had used the photobooks to explain how the activity worked) and affective aspects (the child had displayed enjoyment in showing the photobook to others). Examples of these themes are provided, relating back to the children's participation in the photobook conversation where possible.

Trustworthiness

The quality of this research was enhanced by addressing two components of trustworthiness: credibility and transferability. Credibility provides confidence that the findings of the research are accurate and reflect the perspectives of the participants (Creswell and Poth, 2018). Credibility in this research was established using multiple participants and multiple methods of data collection, where triangulation of the findings was enhanced. Transferability is the extent to which the results can be applied to other similar contexts (Creswell and Poth, 2018). Through detailed descriptions of the methodology, along with a range of multiple and diverse descriptive vignettes, readers can assess the transferability of the research findings to their related situations.

RESULTS

The findings are presented in two sections. The first section describes how the children demonstrated their science understanding using the photobooks. The second section describes how the photobooks were used to home.

How the Photobooks Assisted Children to Demonstrate Their Science Understanding

Four major themes were identified relating to how the photobooks assisted the children in demonstrating their understanding of how the science exhibits worked: providing a context, demonstrating competence, multiple forms of communication, and participation on children's own terms. The first three themes are presented in **Table 3**, highlighting their occurrence across the dyads, and then described in the following sections. The fourth theme is described below.

Providing a Context for Conversation

The photobooks provided the children with a focus for conversation and a context for the questions they were being asked. All 19 children found the photobooks provided them with a visual reminder of the Outreach program and how they had participated in that program. By looking at a concrete representation of themselves interacting with an activity, the children were able to respond to open-ended questions, such as "What are you doing here?" and "How did you make it work?" When turning the pages of her book, one girl confidently stated, "I can remember what we were doing here" (Dyad 5.4), highlighting how the photographs served as a memory aid for what she did in the Outreach program.

Twelve of the children (63%) identified themselves, family, or friends interacting with the exhibits or identified the room in the photographs. Two examples demonstrate this:

> "That's you and me, Mummy. That's me and Mummy." (Dyad 3.2)
>
> "That was me in this room." "That was me in that [pink] top." (Dyad 4.2)

This self-identification reinforced that the book was about them and assisted in connecting the children with their experiences of the program.

Ten of the children (53%) also pointed to specific parts of the photographs to reinforce what they were saying or what was happening. The following example demonstrates how a child used pointing in his explanations.

> Looking at the photograph of himself playing with the cogs, child in Dyad 3.2 states "You take them off and put them there" (pointing to the photograph). Researcher replies, "You remember taking some of the cogs off and putting them in different places."

Additionally, some children chose to point at objects in the photographs rather than respond verbally.

> Researcher: So, you are racing the cars down the ramp. Can you remember which ramp was the fastest? [Name] is pointing to the red ramp. (Dyad 2.2)

These examples demonstrate how the photobooks provided a context to stimulate the children's thinking.

TABLE 3 | Occurrence of common themes across dyads in relation to how the photobooks assisted the children in demonstrating their understanding of how the science exhibits worked.

Dyad number*	Providing a context for conversations			Demonstrating competence		Multiple forms of communication		
	Visual reminder of content	Identifying self, family and friends	Pointing to highlight aspects	What did you do?	How did it work?	Verbal	Non-verbal	Through parent
Dyad 1.1	√	√	√	√	√	√	√	
Dyad 1.2	√			√		√	√	√
Dyad 1.3	√			√	√	√	√	√
Dyad 1.5	√	√		√	√	√	√	√
Dyad 2.1	√			√	√	√		
Dyad 2.2	√		√	√	√	√	√	√
Dyad 2.3	√	√		√	√	√		
Dyad 2.4	√	√	√	√	√	√	√	
Dyad 3.1	√			√	√	√	√	
Dyad 3.2	√	√		√		√	√	√
Dyad 3.3	√	√	√	√		√	√	√
Dyad 3.4	√			√		√	√	√
Dyad 4.1	√	√	√			√	√	√
Dyad 4.2	√	√	√	√	√	√	√	√
Dyad 4.3	√	√	√	√		√	√	√
Dyad 5.1	√		√	√	√	√	√	√
Dyad 5.2	√	√	√	√	√	√	√	
Dyad 5.3	√	√	√	√	√	√	√	√
Dyad 5.4	√	√		√	√	√		√
Total	19	12	10	18	13	19	16	13

**Dyad number refers to playgroup and child/parent dyad. Child in Dyad 1.4 chose not to participate in the conversation, so the total number of children is 19.*

Demonstrating Competence

The photobooks allowed the children to demonstrate their understanding of the science associated with various exhibits of the Outreach program. All but one of the children described what they were doing in the majority of the photographs, with 10 of the children describing what they were doing in all the exhibits. In relation to understanding, 13 of the 19 children (68%) could explain how the majority of the exhibits worked, with three children explaining all the exhibits in which they participated.

When asked what they were doing, most children provided a description. Some children provided detailed descriptions such as "That was me playing with the dogs" (Dyad 3.3) and "I put that one in and I picked that one up. It was floating it was, in the water. If you look closer, see it does sink 'cause it's very big" (Dyad 4.2). Other children used simple descriptions, such as "Looking" (Dyad 1.2) and "Smelling" (Dyad 3.4). The one child who did not describe what she was doing (Dyad 4.1) was quiet and chose to reply "I don't know" to all but one question through her mother.

Many children did not have the scientific language to explain how an exhibit worked. However, through using their own language and body actions in conjunction with the photographs, they were still able to give an explanation that demonstrated understanding. Even when some children used one or two word answers they could demonstrate an understanding of how the exhibit worked. A range of examples are presented below to highlight children's explanations of how exhibits worked.

The following conversation relates to the car ramp:

> Child in Dyad 2.4: You put car there (pointing). It goes really fast if you go there (pointing to red metal ramp). It goes a little bit slow (pointing to other ramps). That one is the fastest (pointing to the red ramp again).
>
> Researcher: Why was that the fastest?
>
> Child in Dyad 2.4: It's nice and smooth. They're bumpy (pointing to the other ramp surfaces).

This child has provided a clear explanation of how the ramps work, using terminology of "smooth" and "bumpy" and pointing to aspects of the photographs to highlight his comments.

The following conversation relates to the cogs:

> Researcher: Can you remember playing with the cogs and the steering wheel?
>
> Child in Dyad 1.1: You turn this one (steering wheel) and it turns these, and they turn each other. They just help, they help.
>
> Researcher: They help each other to turn.

This child talks about how turning the steering wheel results in the other cogs turning. He uses the terminology of "they help" to explain how interlocking cog wheels work.

A third example is a conversation between a mother and child about the balance scales:

> Child in Dyad 4.2: We take one and put it in, and those balancing, and those on the other side and the other one goes on the other way.
>
> Mother: What were the scales doing?
>
> Child in Dyad 4.2: Balancing.

Mother: How did you make them balance?

Child in Dyad 4.2: Put two apples in that one and put two apples in there and it makes it balance.

Mother: What happens if it didn't balance?

Child in Dyad 4.2: (points to picture on page showing not balanced): One up, one down.

In this example the mother is encouraging the child by asking a range of questions. Not only has the child described a balancing situation, she has also identified a situation that is not balanced in the photographs.

Two children engaged in fantasy play (Rennie and Howitt, 2020) when playing with plastic insects (Dyad 1.2 and Dyad 3.2). Both children provided a detailed description of what they were doing. The child in Dyad 1.2 was pretending the insects were Grandma and Grandpa who went shopping and then were having a cup of tea in their holiday house, while the other was making a home for a grasshopper. There was no science explained in relation to the designated activity. The child in Dyad 3.2 demonstrated his previous experience with how insects move and their habitats. He demonstrated how grasshoppers jump and he commented that to make a home for the grasshopper you need "some leaves and some rocks." Further, when asked if the log was the grasshopper's home, he replied confidently "No, it doesn't live in logs. Different animals live in logs."

Those children who did not explain how the exhibits worked tended to give short or one-word answers that described what they were doing rather than providing an explanation. Some children stated, "I don't know". Such answers could reflect that they did not understand how the activity worked, did not understand the question, or simply chose not to provide an answer.

Multiple Forms of Communication

Using the photobooks allowed the children to demonstrate their knowledge through multiple modes of communication: verbal, non–verbal and through their parent. All children described what they were doing using words, although in many cases it was in language familiar to the child. Sixteen of the children (84%) used nonverbal means to communicate, such as gross motor actions to describe how an activity worked, nodding/shaking of head to indicate agreement/disagreement and pointing to emphasize a specific aspect. Thirteen of the children also communicated through their parent. This could be through the parent asking the child a specific question to encourage a response, the parent encouraging a response or the parent interpreting the child's words for the researcher.

This first example highlights a mother questioning her daughter to provide additional information, the use of language appropriate to the child to describe the surface of the mirror ("slimy slopey") and the use of body movement to help describe what is happening (opening the mouth). The researcher, child and mother (Dyad 1.3) were looking at mirror photographs.

Researcher: I really like these [three] pictures here as it is you and your Mum really looking and trying to work out what is happening in these mirrors.

Mother: Do you remember the shape of the mirror?

Child in Dyad 1.3: Yeah.

Mother: Do you remember we were touching it to work out the shape of the mirror? Was it a straight mirror or was it a bit different?

Child in Dyad 1.3: A bit different.

Mother: What did it feel like?

Child in Dyad 1.3: It was slimy slopey.

Researcher: Slimy slopey. That is a really good description.

Child in Dyad 1.3: I liked the one with the funny heads . . . and I had a face like 'aaah' (mouth open).

This example highlights the importance of allowing children to use their own language to describe what is happening.

Although quietly spoken, the boy in the following example demonstrated his understanding of how the car ramp worked through multiple forms of communication. His mother repeated various questions to encourage a reply. Answers tended to be short (especially at the start of the conversation) and included nodding and pointing throughout.

Researcher: Did you like playing with the ramps:

Child in Dyad 2.2: (Nods.)

Researcher: What were you doing here?

Child in Dyad 2.2: Racing the cars down the ramp.

Researcher: Which ramp was the fastest?

Child in Dyad 2.2: (Points to the red smooth ramp.)

Researcher: Why was that the fastest ramp?

Child in Dyad 2.2: Because it is more flatter.

Researcher: Do you know which ramp is the slowest?

Child in Dyad 2.2: (Nods.)

Researcher: Do you want to point to the slowest one?

Child in Dyad 2.2: (points to the other three ramps.)

Researcher: Why were they the slowest ones?

Child in Dyad 2.2: Because they were bumpier than that one (pointing to the red smooth ramp).

There is a clear explanation of how the ramps worked, supported by the body language of nodding and pointing.

Participation on Children's Own Terms

The photobook allowed the children to participate in the conversation on their own terms. Notably, by asking the children if they wanted to turn the page, all children were able to move at their pace or withdraw when they were no longer interested in participating. Four examples demonstrate this.

Once they had started with the photobook and understood the process involved, both children in Dyad 3.3 and Dyad 3.4 turned the pages of the book when they were ready to move on rather

TABLE 4 | Classification of parents' description of how their children had used the photobooks at home.

Dyad number*	Child has shared the photobook	Cognitive		Affective
		Child talked about what they did	Child explained how the exhibit worked	Child's enjoyment in showing the photobook
Dyad 1.1	√	√		√
Dyad 1.2	√	√		√
Dyad 1.3	√			
Dyad 1.4	√	√		√
Dyad 1.5**				
Dyad 2.1	√	√	√	√
Dyad 2.2	√			√
Dyad 2.3**				
Dyad 2.4**				
Dyad 3.1	√	√	√	
Dyad 3.2***				
Dyad 3.3***				
Dyad 3.4**				
Dyad 4.1	√	√		√
Dyad 4.2	√	√	√	√
Dyad 4.3	√			√
Dyad 5.1	√			
Dyad 5.2	√	√	√	
Dyad 5.3	√	√	√	√
Dyad 5.4**				
Total	13	9	5	9

*Dyad number refers to playgroup and child/parent dyad.
**Parent absent from playgroup on day of interview.
***Parent provided limited comments due to children's demands on her time.

than waiting to be asked to turn the pages. Thus, they kept the conversation moving at their pace.

In contrast, two children chose to stop the interview. On the last of nine pages in his photobook, the child from Dyad 1.1 stated, "Okay, I am going to go", and promptly got up and left. Similarly, on page 8 of 16 pages the following conversation occurred with the child from Dyad 4.3:

> Researcher: Should we turn the page again?
>
> Child in Dyad 4.3: No.
>
> Researcher: No. Have you had enough?
>
> Child in Dyad 4.3: Yeah.
>
> Researcher: Yes. That's perfectly alright. We will stop our conversation now. This [photo]book is for you to take home.

Notably, the child in Dyad 4.3 was described as quiet (see **Table 1**) yet still felt empowered to stop the conversation. These examples highlight how the use of photobooks can allow children more control over the photo–elicitation process as they have the power when turning the pages.

Extended Use of the Photobooks at Home

Table 4 provides a summary across the dyads of the number of parents who, during their interview 7 weeks after the Outreach program, mentioned cognitive aspects (the child had used the photobooks to talk about what they did, the child had used the photobooks to explain how the activity worked) or an affective aspect (the child had displayed enjoyment in showing the photobook to others) when discussing how their children had used the photobooks at home.

Of the 15 parents who were interviewed at 7 weeks, 13 referred to their children's cognitive and/or affective use of the photobooks at home. Cognitive themes include the child talking about what they were doing (9 of 13) and explaining how the exhibits worked (5 of 13). The affective theme relates to the children's enjoyment of both the Outreach program and showing the photobook to others (9 of 13). Various parent's comments relating to how their children interacted with the photobook at home are presented below.

Nine parents noted that children talked about what they were doing in the photos, with some children going through every page of the album.

> He showed all his grandparents. "Look at my photos, this is what Mummy and I did during [science Outreach program] coming to playgroup." He loved it and went through every single page; this is what we did here, and this is what we did here. (Parent in Dyad 5.3)
>
> He showed it to his Nonna and Nonno. He showed them the photos and explained that he was interviewed and what he was doing. He showed it to anyone who was happy to see it. All the grandparents made a very big deal of him being in this special book. (Parent in Dyad 1.2)

Both these quotes demonstrate how the children 'owned' the photobook and became the narrator of their story. The significance of the second quote is that it related to a quiet boy who had engaged in fantasy play through most of the program and had spoken in short sentences with the researcher during the photo-elicitation conversation. At home, this child appeared happy and confident to discuss the content of the photobook with his grandparents and his role in the research project.

Five parents also commented on how the children used the photobook to explain how the exhibits worked.

> [Grandparents] are visiting at the moment. So, he's taken it out and shown it to them. He's talked through a lot of things, in particular . . . the one with the feather in the bottle and how that worked . . . and how they were putting the fruit in the weighing thing [scales] and how that worked. (Parent in Dyad 2.1)

> I remember sitting at the table and we did actually talk about what she did, with the photos. As a little 3-year-old, their explanations are amazing. How they explain and how they see it through their eyes. (Carer in Dyad 4.2)

These quotes demonstrate how children's confidence as they share their explanations of how the exhibits worked and how they used them, suggests they are developing a science identity. The second quote highlights how the child's explanation of how the exhibits worked has led to a shift in the grandparent's perception of the capability of the child (in this case, the mother was not available for interview).

Nine parent comments related to their child's enjoyment of both the Outreach program and the showing of the album.

> He tells me what he was doing [in the picture]. He really enjoys looking at himself while he is playing. He remembers that it was fun, and it brought joy to him. (Parent in Dyad 1.1)

> She made a point of [it] when her grandmother came over. "Omma, Omma, have a look." We have a few little photo books at home that we have put her holiday photos in that she has chosen that she likes in her bedroom. She has this [Outreach program photobook] in her bedroom as well. (Parent in Dyad 1.4)

The second quote is significant as it related to the child who did not engage with the photobook at all during the photo-elicitation conversation. In a more familiar context, she was eager to share the book with family and it had pride of place in her bedroom.

DISCUSSION

The purpose of this paper was to describe how individualised photobooks were used to support 3- and 4-year-old children in demonstrating their science learning and developing their science identity through participation in a science outreach program. The use of the individual printed photobooks provided the children with a context for conversation, and allowed them to show their competence, use multiple modes of communication, and to participate in the research on their own terms. At home, the photobooks were used to support children's recollection of their outreach experience in a cognitive and affective manner.

Similar to findings reported by Pyle (2013) and Stephenson (2009), the photobooks in this research provided a context for conversations by focusing the children's attention and reminding them of what they did in the Outreach program. By seeing themselves and their family members in the photographs, the children knew the book was about them and this encouraged conversations. The visual reminder of the Outreach program allowed the children to share and explain what they knew about the science exhibits and how they worked, thus demonstrating their competence. This was evidenced both in the photo-elicitation conversations and at home. Some children who were quiet during the photo-elicitation conversations with the researcher, or did not wish to interact with the researcher, readily shared the content of the photobook with family members when at home.

Young children who are still developing their communication skills may not possess the necessary language to adequately express their understandings (Howitt et al., 2017). The individualized photobooks used in this research allowed the children to utilise different modes of communication: verbal, nonverbal (gestures such as nodding or pointing) and through their parents. Most children used both verbal and nonverbal communication to explain the exhibits in the Outreach program. Notably, children used their own language in the verbal communication, such as the term 'slimy slopey' to describe the concave slope of a mirror. Howitt et al. (2017) have previously noted the importance of accepting children's language and allowing them to provide an answer that makes sense to them. This approach acknowledges children's competence and developing skills. Similarly, Clark (2011, p. 328) recognized young children as "meaning makers" and "skillful communicators" when provided with a range of ways to demonstrate their knowledge.

The use of individualized photobooks allowed the children to participate in the research process on their own terms. By asking the children if they wanted to turn the page, they were able to either move at their own pace or withdraw when they were no longer interested in participating. This embraces a rights-based participatory approach to early childhood research where young children's opinions, agency and ability to make decisions are taken seriously, and they are given opportunities to accept or decline their involvement in the research process (Mayne and Howitt, 2015).

The individualized photobooks provided a mechanism to support young children in retelling their story at home, demonstrating their knowledge of the exhibits and sharing their enjoyment of being involved in the Outreach program. Here, the child was the narrator as there were no words in the photobook. This placed the child in a position of power, with the adult having to listen or ask questions. As the story was the child's own and told with his or her own choice of words or actions, ownership was encouraged. Multiple readings of the book at home provided opportunities and time for children to demonstrate their understanding, share their enjoyment, and re-live their science-related experiences. Katz (2011) also noted the enthusiasm of children at home revisiting their photobooks, engaging in conversations and building on existing relationships in the process. Individualised photobooks taken home provide ongoing opportunities for children to reinforce their cognitive and affective links with the program.

In terms of science identity, the use of individualised photobooks was found to contribute to the development of the children's identity and increase their agency in science and the parent's perceptions of their children as young scientists. Children saw themselves in the photographs and these became the center of the photo-elicitation and home conversations. Through explaining what they were doing and how the activity worked, children could see themselves as capable science learners, thereby reinforcing their science identity. Parents also perceived their children as young scientists, capable of describing and explaining what they were doing in the photographs. This can further reinforce children's science identity. Additionally, multiple readings of the photobook can assist children to internalise their science identity (Katz, 2011). While the photo-elicitation conversation allowed the children to demonstrate their science identity, conversations at home around the individualised photobooks proved a powerful mechanism to enhance that science identity. This has implications for photo-elicitation research around individualized photobooks and consideration of incorporating a "take-home" element into data collection.

This research is limited by the small sample of child/parent dyads who chose to participate and being in only one Australian state, albeit five varied locations. It is worth noting that research into children's interactions in playgroups is complicated by the nature of the environment. Although there may have been about 20 children in each playgroup, space logistics meant that it would not be possible to video-record sufficient data for more than 3–5 children during the period of exhibit interaction. A further limitation is that the information gathered in the 7-week parent interviews is restricted by what the parents could remember about how the photobooks were used at home. The photobooks could have been used at home in other ways not noticed by the parents and therefore have not been reported here. Finally, only mothers participated in this research. Fathers may have interacted differently with their children during the Outreach program and noticed different things at home when the children were sharing their photobooks.

It is worth noting also that science identity is a construct, not a visible characteristic of the child. By observing what children do, listening to them talk, hearing about parent's thoughts and their interpretations of their child's behaviors, we have inferred that participation in the science outreach program, supported by the photobooks used in our research process, has provided effective opportunities for children to develop their science identity. On this basis we conclude that our research has highlighted how the use of take-home individualized photobooks that capture children interacting with various exhibits from an Outreach program has assisted in developing children's identity and increasing their agency in science and the parent's perceptions of their children as young scientists. The question of whether the photobooks should have words or not is interesting but moot. With words present, there can be a shift from the child telling the story to the adult telling the story, and thus the ownership of the story is no longer with the child. While the addition of words may be powerful in providing information about the photographs, we suggest that ownership of their story can assist children in creating a science identity. The photobooks present a valuable approach to extending the 'shelf-life' of outreach programs because they allow children to continue their science conversations at home and rehearse their science-related experiences.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Research Ethics Committee, The University of Western Australia. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CH and LR conceived and designed the project of which this study is part. CH prepared the photobooks and analysed the children's data. LR analysed the parent data. CH wrote the first draft of the manuscript. CH and LR both contributed to manuscript extension and revisions, read and approved the submitted manuscript.

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Co-Designing for Equity in Informal Science Learning: A Proof-of-Concept Study of Design Principles

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Informal science learning has great potential to engage diverse learners, but faces issues of persistent inequities. While systemic change is needed to address these issues at a structural level, there is also a need for practical tools to support the organisations and the educators who are working to engage audiences in informal science that is authentic, culturally responsive, interest driven and learner centered. This article presents a collection of design principles, generated through a design approach which actively involved informal science learners, practitioners and researchers from nineteen countries as contributors. We present the design approach adopted, and suggest that participatory design methods could play a role in supporting equity efforts in informal science learning since several of the educators involved in the process decided to adopt participatory methods in their own practice. We also present an overview of the design principles generated through this process, and discuss the application of an early draft of these in an authentic informal science education programme. By adopting and adapting these principles and approaches in their practices, educators can work towards creating equitable and transformative informal science learning environments and experiences.

Keywords: informal science learning, equity, science communication and dissemination, co-design, design principles

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INTRODUCTION

Digital and physical spaces beyond the boundaries of formal education hold myriad opportunities for creative engagement with various combinations of science, technology, engineering, mathematics and the arts (Falk, 2001; Sacco et al., 2014; Bicer et al., 2017). As such, science learning in these out-of-school settings is extremely diverse (O'Donnell et al., 2006; Falk and Dierking, 2012). Such activity is referred to as free-choice (Falk, 2005), non-formal (Garner et al., 2014) and informal (Bell et al., 2009) learning. Drawing from the literature situated across this broad field, we will refer to the educational context of these experiences as informal science learning. Informal settings that offer such learning opportunities can promote curiosity, inquiry and exploration, and embrace learning that includes learner interest, engagement, and identity-building (Allen and Peterman, 2019). Despite the great potential for informal science learning to engage a broad range of learners (Sacco et al., 2014; Dawson, 2018), particularly those underserved by formal science education, there is persistent evidence that these spaces do not engage effectively with a diversity of communities; rather, they reinforce the dominance of particular societal groups and the culture of science (Dawson, 2014a; DeWitt and Archer, 2017; Dawson, 2018; Godec et al., 2021). Archer and colleagues assert that within informal science learning activities, equity is determined not only by underlying norms and values, but also by the extent to which it does or does not reproduce pre-existing social structures and power relations. Greater support for organisations and educators in the informal science learning sector can change the field fundamentally and realise equitable impacts on youth. (Archer et al., 2021).

The perspective presented in this paper emerges from a European Commission funded project SySTEM 2020 (2018–2021) which examined science learning outside the classroom through a number of lenses across 19 countries in Europe and the Middle East[1], covering learners between 9–20 years from various backgrounds. The research presented here incorporates design traditions to support informal science educators' work towards equitable science learning. This project uses co-design to foster diverse stakeholders' active involvement to develop tools that support equity in informal science education.

Co-design builds on the user-centered design tradition and is strongly aligned with approaches that advocate for the active participation of the design beneficiaries to ensure relevant and usable design solutions (Sanders and Stappers, 2008; Durall et al., 2020a). The design beneficiaries are referred to as stakeholders and include all those who would be directly and indirectly affected by the design solutions. The call for actively involving a diversity of stakeholders in the design process is based on the recognition that people are creative and experts of their own experience (Sanders, 2002). Co-design has been considered a valuable approach to support stakeholders' collaboration, ownership of design solutions and ultimately, empowerment (Tissenbaum et al., 2012; Kwon et al., 2014; Matuk et al., 2016; Durall et al., 2020b). In the mid and long term, participatory approaches like co-design are claimed to lead to more sustainable solutions with high levels of adoption (David et al., 2013; Treasure-Jones, 2018).

This paper offers a perspective on the development of a design-based solution to support equity in the informal science learning sector. In the following sections, we present results obtained from testing a proof-of-concept of the emergent solution in one setting, and provide a discussion of the potential value of co-design approaches to support science learning beyond classroom settings.

DESIGN PROCESS

This project followed a design approach to generate solutions to some of the most common challenges facing science educators in informal science learning settings. The design process included several rounds of iteration to ensure the stakeholders had the opportunity to influence the outcomes.

To gain a broad understanding of the research problem, the initial phase of the design process consisted of an inquiry into the context (Penuel et al., 2007; Leinonen et al., 2008). During this stage, the design researchers conducted a rapid ethnography (Millen, 2000) to identify main challenges and opportunities for learners and educators in informal science education. Activities in various settings, including museums, science centres, maker and hacker spaces, science fair and summer camps were observed and the participants were interviewed (see **Table 1**). The results of the contextual inquiry highlighted learners' socio-cultural barriers to access and actively participate in science learning—for instance, challenges to develop science identities and sustain interest over time. These findings informed the themes and methods used in co-design sessions with learners, educators and science education stakeholders in a two-day event in Helsinki in March 2019.

The co-design sessions gathered 51 people from 19 countries across Europe and the Middle East (**Table 1**). During the sessions, design-thinking methods were used to support participants to develop a shared understanding of issues and challenges for informal science educators and learners in terms of a) inclusion; b) engagement; and c) assessment and recognition of learning. Once a shared vision on these issues was established, the participants started to define key challenges and opportunities, and to ideate solutions to these challenges. To ensure diversity of viewpoints, each of the co-design session teams included learners, educators and other stakeholders. The methods used included concept mapping, identification of opportunities and challenges, card sorting, clustering and prioritisation. During the ideation phase, the participants brainstormed and sketched their ideas.

The outputs of the co-design sessions were analyzed and interpreted using design synthesis methods by the research designers. Design synthesis is an inference-based sense-making process through which designers look at the data from multiple perspectives, make relations and generate new ideas (Kolko, 2007). This process was iterated until a set of design principles could be formulated.

A first draft of the principles was shared with the SySTEM 2020 partners and external stakeholders, who were all asked for feedback through questionnaires and in workshop sessions (see **Table 1**). The feedback provided in each of the sharing sessions informed further refinement. The design principles underwent three iterations before a final version was released, this process is summarised in **Table 1**

RESULTS

Design Principles

A design principle is a proposition that works as the foundation for designing systems, services or products (Fu et al., 2015). In this instance, the design principles[2] were developed as a resource that provides inspiration for the design, facilitation and assessment of informal science learning activities and programmes.

A set of principles for designing science learning activities and programmes that cultivate involvement in an equitable way was considered valuable in order to meet the varied challenges that educators experience—the difficulties for broadening access and diversity to programmes, the struggle to support regular and continued engagement, as well as the need to master multiple skills. However, as the co-design participants acknowledged, the

[1]SySTEM 2020: https://cordis.europa.eu/project/id/788317

[2]The final version of the design principles is available at: https://system2020.education/resources/design-principles-and-methods-toolkit-for-supporting-science-learning-outside-the-classroom/

TABLE 1 | Summary of actions conducted during the SySTEM 2020 design inquiry.

phase	Action	Participants/actors
Contextual inquiry	Rapid ethnography of science learning in informal learning settings in Finland.	*n* ~ 200 (learners; parents /guardians; educators; makers; civic/ professional organisations)
Co-design	Helsinki co-design sessions.	*n* = 51 (learners aged 18–21; learning sciences researchers; educators/ pedagogical coordinators from informal science learning organisations, civic/professional organisations)
Studio work	Synthesis of the Helsinki co-design sessions key ideas. Formulation of the design principles.	Design researchers
Feedback and evaluation	Workshop session.	*n* = 15 (learning sciences researchers; educators/pedagogical coordinators from informal science learning organisations)
Studio work	Revision of the design principles.	Design researchers
Feedback and evaluation	Assessment questionnaire.	*n* = 15 (as Feedback and evaluation workshop)
Studio work	Revision of design principles.	Design researchers
Feedback and evaluation	Co-design workshop on making in Finnish public libraries	*n* = 14 (library staff workers)
Feedback and evaluation	Assessment questionnaire.	*n* = 20 (as Feedback and evaluation workshop)
Studio work	Iteration and final version release of the Design Principles.	Design researchers

needs, expectations and contexts in which informal science educators work are so diverse that a one size fits all solution is extremely challenging. As one of the educators expressed, the same methods might work very differently depending on the context: “Different approaches can produce the same outcome in different setting, or the same approach can produce opposite results depending on specific features of different context: understanding and respecting the subtle diversities of contexts and learning environments is a cross-cutting aspect that one should never forget”. In recognition of these varied needs, the design principles have been proposed as a starting point for educators, requiring adaptation based on the specific context and needs.

The different expectations of educators, practitioners, researchers and designers translated into conflicting views regarding the approach and level of detail of the design principles. While there was consensus in moving away from prescriptive approaches, there were tensions regarding the level of openness of the principles. The adoption of an iterative approach with several rounds of assessment and feedback helped to reduce the tensions by progressively addressing some of the key demands.

The design principles are categorised in three areas based on their main design focus: *Design for Everyone*, *Design for Experience and Design for Growth* (see **Table 2**). *Design for Everyone* highlights the need to consider aspects connected to access, diversity and inclusion in order to develop equitable practices in informal science education. In a way, the principles included in this area are foundational for all the others.

Design for Experience elaborates on aspects that contribute to creating learning experiences that are meaningful, engaging, inspiring and that foster learning, in which facilitation and the design of social learning environments are central.

Design for Growth seeks to encourage thinking in the longer term. This area calls attention to supporting autonomous learning, identity-building, and lifelong learning.

Each area features three or four design principles, each further supported by several methods (see **Table 2**). The methods are intended to support practitioners to apply the principles in practice and they are accompanied by quotes from the contributors, who are educators and pedagogical coordinators in informal science learning organisations. The quotes provide indications about how to frame practice, as well as specific and practical advice based on the educators’ first-hand experiences. For instance, the quote “You can’t expect people disengaged with science to visit you. You need to take your education work out to where your audience is” is a call for taking a proactive attitude when seeking to increase access and participation. This supposes a change from strategies based on increasing dissemination efforts without reconsidering the channels and venues through which people are expected to access the information. On a more concrete level, the quote “Use your participants’ local cultural knowledge, such as well known stories or myths as starting points for informal science learning activities and experiences. It is surprising how relevant topics can be co-opted to make rich learning opportunities” works as a strategy example for developing culturally responsive practices. To illustrate how the design principles can be applied, real-world cases are included alongside the methods.

In the next section we present the design principles proof-of-concept in the context of an informal science learning programme in Ireland.

Proof-of-Concept

In order to test the helpfulness of the design principles in a realistic context, they were used to aid the internal review of a digital learning curriculum offered by Science Gallery at Trinity College Dublin, a cultural space focused on engaging young adults in conversations about science and art (Gorman, 2020). The learning programme aimed to engage and support 14–16 year olds to use science to generate solutions to a locally relevant societal problem, and consisted of a collection of workshop guides and resources.

The design principles were shared with relevant staff in summer 2020 to guide the review of a digital learning programme, together with a checklist of questions which adapted the principles into self-review prompts. For instance, the principle *Make it accessible* was translated into: “*Does the workshop span a variety of senses and ways of exploring?*”.

TABLE 2 | Design principles for supporting science education in out-of-school settings.

Area	Design Principle	Methods
Design for Everyone	Make it accessible	•Being approachable. •Accommodating diverse needs.
	Embrace diversity	•Showing the diversity of people who engage in science. •Fostering diversity among participants.
	Be inclusive	•Developing empathic understanding. •Becoming culturally responsive.
Design for Experience	Make it matter	•Showing the relevance of science. •Building on personal interests.
	Keep it engaging	•Triggering positive emotions. •Making concepts tangible. •Encouraging open-ended exploration.
	Inspire and motivate	•Guiding learning. •Fostering learners' self-confidence.
	Build social learning environments	•Encouraging sharing and collaboration. •Cultivating a community feeling.
Design for Growth	Create pathways	•Creating continuity and multiple entry points. •Bridging different disciplines.
	Support identity building	•Recognizing learners' achievements. •Raising awareness of possible futures.
	Promote learner autonomy	•Supporting learning to learn. •Boosting transversal competencies.
	Assess your practice	•Setting goals and monitoring progress. •Reflecting on your practice.

The two educators who reviewed the workshop guides using the prompts and the design principles were interviewed in order to explore their experiences using the prompts, and the usefulness of the principles in reviewing the programme curriculum. The interviewees were experienced science educators, who had ten and two years experience in informal science education and communication respectively. During the interview, they explained that they worked together to apply the checklist to the workshop guides that made up the programme curriculum. They reported that they used the questions for "refining workshop guides with design principles in mind" in a structured manner. In particular, they created "a spreadsheet with a column for each concept" to help them to lead "a discussion about each workshop session that we've been reviewing".

They found the reframing of the design principles into a checklist useful, since this format seemed to easily facilitate a reflective discussion about the workshop guides. As one of the educators highlighted, "the open self-reflection questions got us in the right frame of mind". Together, they checked for at least one example of each prompt being satisfied within the curriculum, though frequently multiple were found or aimed for. If no examples were found, they worked to integrate the principle into the activity through tweaking or expanding the existing content or approaches.

During the interview, the educators described the design principles as providing a "different lens on the activities that we are doing", demonstrating the value of a detached framework that can be used to highlight strengths as well as areas for improvement in curricula before they are implemented. They described the design principles as a self-checking mechanism which offered a new perspective on planned activity. For instance, as one of the educators acknowledged, the checklist helped them to consider the diverse needs of participants: "One thing I remember taking note of (from the design principles), was . . . some of the workshops use digital tools . . . Some students with special educational needs might find new digital tools a bit overwhelming, and that is something which we didn't consider".

Though the interviewees appreciated the checklist as a helpful and reflective tool to aid their work, they also found it somewhat challenging to apply. As one of them phrased it, "We struggled sometimes . . . we used it as a way to check everything we did and it was hard to make a statement that one specific way was the right way". Moving from the general (the design principle) to the specific (decision-making and practice in a learning environment) was perceived as a challenging, yet rewarding task. The feedback provided during the proof-of-concept testing and interviews was taken into consideration for the final version of the design principles.

DISCUSSION AND CONCLUSION

The preceding sections have introduced the design approach, the resulting design principles for informal science educators, as well as the implementation of the principles in an authentic setting as proof-of-concept. This section reflects on the approach and results to suggest some implications for research and practice.

First, collaborative design helps to include a diversity of voices and perspectives and cultivates equitable practices. While the participation of diverse science learning stakeholders helped to build a shared understanding of the challenges and opportunities that learners and educators face in informal science learning settings, the process was not exempt from tensions due to the stakeholders' different needs. During the development of the design principles, the adoption of a co-design approach helped to acknowledge these gaps and negotiate the solutions (Bønnelycke et al., 2018). The proof-of-concept testing of the design principles was part of this process of progressive refinement through iterations. Based on the SySTEM 2020 experience, we may say that the co-design process also provided learning opportunities for stakeholders by showcasing tools and methods for collaborative[3] design. As one of the participants expressed after the co-design event in Helsinki: "I have the impression that the co-design session has been a great chance, for a variety of people, to experiment (*sic*) a deep moment of debate and reflection. Such . . . moments are particular for several reasons: the international breadth, the importance and the quality of the content presented and debated, the experience of the structured facilitation of such big groups". Following the process, several practitioners have started using co-design with their teams and communities to foster diversity and inclusion. We consider this is an important impact that aligns with findings from other studies in which co-design processes have been used to support equitable teaching and learning (Penuel, 2019).

Secondly, we reflect on the challenges for developing tools that move from the general (the principles) to the particular (the context of a specific informal science learning setting and its learners). As presented in the proof-of-concept, the design principles provide general guidance to inspire practice in a broad range of science in out-of-school settings; the intention is to be independent of learner demographics, pedagogical framework or learning design methodology. The checklist created by the educators at the proof-of-concept testing phase acted as an intermediate tool to translate the design principles and make them usable for educators with diverse backgrounds and levels of experience. While the principles were highly appreciated, the process of translation—in this case in the form of a questions checklist—is an important step that would benefit from further iterations and requires the active involvement of the educators who are expected to use the tool. Based on the proof-of-concept, we consider that the translation work benefits from following a collaborative approach. Further work involves developing specific actions with learners for translating the principles into practice.

Third, making meaningful progress towards equity in informal science education requires awareness of the complexity of the issue. Inequity in science is reinforced when those designing experiences lack the tools to think critically about who they are trying to engage, and who they are (perhaps unintentionally) excluding (Dawson, 2014a; Dawson, 2014b; DeWitt and Archer, 2017). While fostering awareness amongst science educators in informal learning settings is important, the responsibility to advance equity work should not fall to or rely upon specific individuals. The efforts supporting equity should be framed as part of a collective endeavour that involves the whole science learning community. The design principles should be understood as part of this collective effort.

Finally, to understand the complexity of considering inequity in informal science education we suggest looking at it as a "wicked problem". In particular, wicked problems are complex and challenging because they are ill-defined, with multiple interconnections and conflicting interests that change over time (Dillon, 2017). Finding solutions to wicked problems is difficult because quite often solving one part of the issue creates other problems (Rittel and Webber, 1973). The educators who reviewed the science educational programmes using the checklist of questions struggled because it was challenging to know if "one specific way was the right way". This observation aligns with the claim that answers to equity problems cannot be assessed from a "right or wrong" perspective, since solutions are always incomplete and need to be constantly reviewed (Rittel and Webber, 1973). We consider that the adoption of co-design processes, as well as the use of tools like the design principles presented in this paper can help to cultivate equity-oriented practices. While modest, such a tool can contribute to a necessarily systemic change that is required to address inequity in science.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because it is not possible to guarantee the anonymity of the research participants. Requests to access the datasets should be directed to, mairead.hurley@tcd.ie.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ED led the conceptual design of this manuscript. ED, SP, MH, EK, and TL wrote the initial drafts collaboratively. ED led the design research intervention in the field, SP actively contributed to the proof-of-concept study. MH and ED designed the research project within which this work was realised, and MH coordinated this project. All authors reviewed the manuscript and provided comments and feedback.

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[3]More information about the co-design sessions can be found in Durall et al. (2020a).

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Zines as Reflective Evaluation Within Interdisciplinary Learning Programmes

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This paper presents a unique method for documenting and reflecting learning in interdisciplinary science learning settings, which prioritises the perspectives of marginalised learners and which may be used across cultural contexts. Short for "magazine" or "fanzine," zines are small DIY booklets which can contain poetry, narrative, drawings, comics, collage and more. Often associated with radical or alternative cultures, they can become a kind of self-made soapbox for the creator, a material artifact that, by its very deconstructed and deconstructing nature, encourages a personalised remixing of ideas. Within this paper, we examine the practical and pedagogical positioning of zines within a STEAM (Science, Technology, Engineering, Arts, and Mathematics) context. As both a visual and text-based artifact, a zine is uniquely capable of capturing broad responses to diverse learning experiences which blur disciplinary boundaries and offers an inclusive and firmly emancipatory approach to reflective practice.

Keywords: informal science learning, STEAM (enriched with arts), equity, reflection, social justice, evaluation, widening participation

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INTRODUCTION

Science learning that takes place in out-of-school settings has been an active area of research for several decades (Falk and Dierking, 2000; Braund and Reiss, 2004). In recent years there has been a renewed focus on how science learning in these settings may have a greater impact on lifelong learning by strengthening partnerships between formal and informal educators, supporting social learning, and providing greater freedom for people to choose how and when they engage with science (Dunlop et al., 2019). Different pathways for learners, or learning ecologies, can cover a wide range of learning environments but often focus on children and school-related programmes rather than higher education and adult learning (Sangrá et al., 2019). The need for broader considerations of science learning is reflected in the growing number of conceptualisations across the field, which often highlight participatory approaches such as citizen science, co-creation, and inclusive science communication (Durall et al., 2020; Polk and Diver, 2020; Roche et al., 2020).

A key focus in the development of participatory theoretical frameworks for informal science learning is giving appropriate consideration to the role of location and community, especially for marginalised youth who face systemic barriers to inclusion (Dawson, 2018; Nazar et al., 2019). Informal science learning programmes have traditionally focused on how these groups can be better supported to improve their access to science education outside of the classroom (Calabrese Barton and Tan, 2018). Rather than aiming to change how young people engage with science in out-of-school settings, it is becoming increasingly clear that it is the field of informal science learning which must change in order to support more equitable participation (Archer et al., 2021).

Learning environments must find common ground between scientific knowledge and cultural knowledge (Gondwe and Longnecker, 2015). This will improve how western science interacts with sociocultural learning and indigenous ways of knowing and being (Tzou et al., 2019). Such cross-cultural conceptualisations of how learners engage and communicate science are important for dismantling infrastructures of exclusion (Orthia, 2020). This is especially pertinent for the most vulnerable groups in society, such as migrants and refugee populations. In addition, the responsibility for more equitable and inclusive practice extends not only to museums, science centers, zoos, and aquariums, but to all informal science learning spaces (Brown et al., 2020). Along with inclusive environments, more robust and reliable research methods are needed to evaluate and assess science learning in out-of-school settings, especially those evaluation approaches which are responsive to the lived experiences and voices of non-dominant communities (Garibay and Teasdale, 2019).

This paper describes one such method, a unique approach to reflective evaluation, which prioritises the perspectives of marginalised learners and may be used across cultural contexts in informal and out-of-school settings.

It addresses the research question: How might reflective learning be facilitated and documented across interdisciplinary settings and cross-cultural contexts?

This approach uses zines—handmade booklets which may contain poetry, comics, collage, drawings, and more. Zines offer a highly creative and personalised way to explore, critique and reflect upon a given topic through multiple means (Radway, 2001). Here, the historical evolution of zines and their development as a creative and informal way to carry out reflective evaluation is introduced. Zines are then examined within the context of a STEAM-orientated pedagogical framework and a method of engaging young people in multiple interdisciplinary science learning environments. The paper shares a number of examples from the development period of the tool as a medium of reflection and concludes with recommendations on how this approach can be implemented by researchers and practitioners in the STEAM learning field and beyond. We suggest that the method presented in this paper is flexible enough to be adapted for use in other out-of-school learning programmes and contexts, such as science centers or natural history museums, cultural heritage or the arts.

Radical Roots: A Brief History of Zines

While small circulation ephemera such as political pamphlets, leaflets, and flyers have a long and varied history, there were a number of critical moments which defined the zine format and movement. In November 1926, a group of individuals solicited contributions for a unique, non-commercial publication, FIRE!! This small circulation periodical included artwork, poetry, and essays from great thinkers and revolutionaries of the Harlem Renaissance (FIRE!! 1926). It chronicled and celebrated black excellence and explored subjects such as queerness, and femininity, subjects which mainstream publications often refused to cover. Financed by its creators, including celebrated authors Langston Hughes, Zora Neale Hurston, Aaron Douglas, Richard Bruce Nugent, and Wallace Thurman, the independent publication allowed young black artists to represent their values, ideas and experiences (Johnson and Johnson, 1974). Although short lived, the publication created a lasting impact. While the youth of the Harlem Renaissance were excited by the radical perspectives on queer romance and political criticism, other readers were appalled. In the excitement following this fierce debate, other "non-commercial non-professional small circulation publications" known as zines appeared Duncombe, (1997), including *Harlem* and *Black Opals* (Johnson and Johnson, 1974).

In the 1930s and 1940s, science fiction fan clubs such as the Science Fiction League (SFL) further popularised the zine medium (Bretnor, 1974). SFL members came together to discuss and rework stories in their own periodicals published within their community. They became a tool for women in particular to critique and reimagine popular stories from a feminine point of view, or to feature leading female characters (Radway, 2011; Vong, 2016).

Zines experienced another wave of popularity in the late 1960s and throughout the 1970s, playing a critical role in the dissemination of anti-establishment and feminist ideology in the United States and the United Kingdom (Garrison, 2000; Chidgey, 2009). As Punk and D.I.Y scenes emerged, and the rise of copy shops provided greater distribution powers to zine creators, publications such as *Sniffin' Glue* and *Profane Existence* leapt from the counterculture movement and into the mainstream (Duncombe, 1997; Bartel, 2004). In each historical iteration, zines provided an intellectual space outside of the mainstream. Where creators did not see themselves, their experiences, values or identities represented, zines provided a new kind of public sphere where communities could be found or created with little more than paper, ink, and a few old magazines. (Bleyer, 2004; Guzzetti and Gamboa 2004).

Contemporary Zine Culture in Education

More recently, zines have seen a resurgence in popularity both online and in paper form. These roots in civic engagement, critical analysis and personalisation have produced a powerful reflective tool which allows learners to represent themselves and construct meaning through multiple visual and textual means (Guzzetti and Gamboa, 2004; Poletti, 2005). As zine creators, the medium positions learners not as consumers of knowledge, but as critics, creators, and crucially, experts in their own communities of knowledge (Yang, 2010; Desyllas and Sinclair, 2014). With pen and paper, anyone can become a zinester (someone who makes zines). This material accessibility makes zines an ideal tool for learning contexts where technological resources are limited (Guzetti, 2009; Guzzetti and Gamboa, 2004; Knobel and Lankshear, 2002).

Researchers Rallin and Barnard (2008) brought zines into formal learning spaces, including university courses on literary analysis and composition. Here they used zines to encourage students to "to interrogate how knowledge serves specific

EXPLORING	MEANING-MAKING	CRITIQUING
Noticing & questioning	Producing representations	Hacking the ideas of others
Exploring materiality	Engaging multiple modalities	Cultivating dissent
Defining the problem space	Finding relevance	Holding commitments to the standards of the field
		Sharing results & audiencing

FIGURE 1 | Framework for using zines as a STEAM learning and reflective tool. Adapted from (Mejias et al., 2021).

political, and social interests, to cultivate a questioning relationship to their own knowledge and to dominant modes of knowledge dissemination" (Rallin and Barnard, 2008). DeGravelles (2011) found that zine pedagogy has been used across formal and informal learning settings as a way to empower students through accessibility, self-authorisation, and participation.

A number of science communicators and educators have also experimented with this medium (Dunwoody, 1992; Yang, 2010; ScienceGrrl, 2018; Liu, 2019) encouraged his biology students to go beyond consuming scientific knowledge, by creating zines which invited critical responses and reimaginings of scientific concepts and phenomena. This kind of participatory literacy encourages learners to take possession of knowledge and find new ways to explore, explain and apply these ideas. "In a world where scientific knowledge is increasingly complex and technical, the participatory literacy of zines can foster a sense of ownership that is often lacking for those who don't have the chance to study science formally or at an advanced level, or who had a bad experience with science learning in their educational past" (Yang, 2010).

PEDAGOGY

Zines as a Science, Technology, Engineering, Arts, and Mathematics Pedagogy

STEAM (Science, Technology, Engineering, Arts, and Mathematics) is a term used to describe a growing field of research and practice that includes the arts among the more commonly combined STEM subjects (Liao, 2016). A number of recent studies have highlighted the transformative learning potential of informal STEAM programmes (Costantino, 2018; Lee and Soep, 2018; Bevan et al., 2020a). The creative inquiry model of STEAM learning presented by Costantino (2018) builds on the problem-based, inquiry-based, and hands-on learning features of STEM education, alongside the arts and design "signature pedagogy" which features the key areas of critical making and object-based learning, critique, and exhibition. This creative inquiry model "demonstrates a mutually engaged transdisciplinary approach for STEAM learning" (Costantino, 2018, p.6). In their thorough overview of the various contested conceptualisations of the term STEAM, Mejias et al. (2021), (p.209) also feature the word "mutual", concluding that STEAM has the most potential for positive impact when the arts is given equal status among the STEM subjects, and both are "mutually instrumental" to one another. Bevan et al. (2019) and Mejias et al. (2021) present a framework of conjectured STEAM epistemic practices developed through observation of out-of-school transdisciplinary art and science programmes for youth, including those in Science Gallery Dublin described in *Learning Environments and Methods*. We adopt a version of this framework, modified by us, as a pedagogical model within which to position zines as a STEAM learning and reflective tool (**Figure 1**).

The zine-making sessions outlined in the subsequent sections of this paper asked students to reflect on their learning within an informal STEAM environment and are designed to surface these epistemic practices of STEAM in their own right, as described in the following questions that a zine-maker may ask themselves during one such session. These questions were developed specifically for the zine activity and highlight the adaptability and flexibility of the STEAM pedagogy framework of Mejias et al. (2021). This provides an example of how practitioners may examine the STEAM potential of their proposed activities under the three strands of this framework: exploring, meaning-making and critiquing.

Exploring

1. Noticing and questioning-what and when did I learn? Who did I learn from/with? How did I learn?
2. Exploring materiality-what materials shall I use to create my zine? Can I improve and personalise my zine by adding different materials?

3. Defining the problem space-which element of my learning shall I focus on in this tiny booklet? What feels personally important enough to capture? How much detail can I go into?

Meaning-Making

1. Producing representations-how do I convey my message? Can I represent feelings and emotions visually, in text or using materials?
2. Engaging multiple modalities-Can I use text, visual art, digital media, even tactile or embodied representations to embellish or accompany my zine?
3. Finding relevance-can I show the relevance of the topic or the learning experience to my own life, my identity? What are the broader social, cultural, political implications of the topic that affect me, my social group, my family, my country?

Critiquing

1. Hacking the ideas of others-can I remix or repurpose the ideas I have encountered, and combine conjecture and hypothesis to create personal relevance and meaning? Can I use the tools I have at my disposal to be creative?
2. Cultivating dissent-what is my own personal reaction to these ideas? What is the implication of my learning experience? Do I have critical agency?
3. Holding commitments to the standards of the field-what is a zine? Who has used them in the past and why? Does my zine share the features and form? Am I a "zinester?"
4Sharing results and "audiencing"-am I ready to share my personal creation with the world?

Zines as Reflective Tools in Informal Learning Spaces

Rather than simply offering an opportunity for learners to recall or recite educational experiences, when paired with effective prompts or provocations, zines encourage their creators to reflect deeply on the implications of their learning experiences and to situate them in their own contexts. Reflection can be understood as an active cognitive process in which a learner deliberately contemplates an experience (Dewey, 1933). This process provides opportunities for learners to seek and find connections between previous knowledge and experiences (Di Stefano et al., 2017).

As a result of the level of engagement from learners that reflection requires, it is used as a key practice within education research across formal, non-formal, and informal learning environments (Williamson, 1994; Congdon and Blandy, 2005; Yang, 2010; Moore et al., 2020). Though reflection can be difficult to capture, learner-made zines offer a rich insight into learners' personal learning processes. Together with prompts, zines offer a structured form of reflective support and as such are more likely to be accessible for many participants (Carlile and Jordan, 2007). Researcher and educator ToddHonma, (2016) (p.33) has noted, "Because of their do-it-yourself ethos, zines are often embraced by those from marginalized backgrounds because of their freedom to experiment with different modes of writing, expression, and presentation." While other mediums such as annotated portfolios Löwgren, (2013); Hall, (2020), user stories Cohn, (2004); Matuk et al. (2016), autoethnographies Tutkal et al. (2021); Souto-Manning, 2010) also support learner-led reflection, zines offer learners a sense of subversion and ownership that other more institutionalised forms of writing do not provide (Lonsdale, 2015). Zine-making encourages multimodal composition, transdisciplinary exploration, and participatory culture in creating pieces of work which are meant to draw attention to what is meaningful and impactful to their creators (DeGravelles, 2011; Lonsdale, 2015).

In order to explore the levels of reflection which emerge during the zine-making process, this approach adopts the Ryan and Ryan (2015) 4R Reflection Scale: reporting/responding, relating, reasoning, and reconstructing. Reflection may be represented in many forms and a straightforward categorisation was proposed by Ryan and Ryan (2015) to help researchers fathom the depths of reflection encouraged or discouraged by a medium. **Figure 2** demonstrates how the text in zines (column 1) might correlate to the different depths of reflection described by Ryan and Ryan (2015) (column 3).

LEARNING ENVIRONMENTS

This paper shares the experience of developing and using zines within inter-or transdisciplinary learning programmes hosted by Science Gallery at Trinity College Dublin (Ireland)[1], Ars Electronica (Austria)[2], Waag (Netherlands)[3], Kersnikova Institute (Slovenia)[4], and LATRA (Greece)[5]. These institutions offer learning experiences that are situated beyond the formal classroom environment, and as such offer free-choice (Dierking, 2005; Falk, 2005), or informal (Bell et al., 2009) learning opportunities. Together, they serve learners from an array of backgrounds with diverse educational experiences, aged between 11 and 21. For example, LATRA serves young people who are refugees or migrants; their zine workshops specifically engaged learners aged 16–18, two of whom were unable to read and write as they had never attended school. Science Gallery Dublin's STEAM workshop series serves young people in full-time education, aged 15–17, who are taking one week out of school to attend these STEAM workshops, while Waag's program is a weekend school for disadvantaged children in Amsterdam aged 9–14. At the Kersnikova Institute, learners aged 10–14 participated in a weeklong series of programming and robotics workshops. The unifying factor between these locations is a pedagogical approach which combines one or more STEM subjects with the arts, and meeting the criteria set out by Mejias et al. (2021) of being mutually instrumental and

[1]https://dublin.sciencegallery.com/
[2]https://ars.electronica.art/news/en/
[3]https://waag.org/en/home
[4]https://kersnikova.org/en
[5]https://latra.gr/

WHAT YOU MIGHT SEE (in a learner's zine)	WHAT THIS EXEMPLIFIES	WHAT THIS MEANS (depth of reflection)
"Today we did a drama workshop about space" "I learned how to..."	Describing an incident or experience	Reporting / Responding
"I realise now that some of the choices I have made about buying food and clothes in the past were not very sustainable"	Drawing a relationship between the event and prior experiences or knowledge	Relating
"We rely on plastic but it has so many issues, including pollution and health problems"	Considering broader ethical, social or political factors and impacts	Reasoning
"I think using science and art together can really change future technology" "Tomorrow I will..."	Developing a plan, hypothesis, model or imagining future actions or developments	Reconstructing

FIGURE 2 | Reflection framework to evaluate reflection in zines, based on Ryan and Ryan 4Rs (2015) including levels of reflection and textual examples.

pedagogical, with neither the arts or the STEM discipline given precedence over the other. The learning design of all of these STEAM programmes promotes learner autonomy and agency through problem-solving, open-ended discovery, and exploration. Programmes are anchored around societal issues and challenges, with learners frequently asked to attend to the ethical, political or economic dimensions of a STEAM-related topic. There is also a focus on facilitation as a process which supports young people in their own construction of knowledge and meaning, rather than direct instruction. These features support the development of "learning as an activist project" Bevan et al. (2020b), (p. 3) in informal STEAM settings, empowering youth to be "critical thinkers and agentive individuals." Considering the historic use of zines for political action and engagement, they are a useful tool in such environments where learning is considered activist, thanks to their ability to support ownership of and meaningful engagement with STEAM knowledge.

METHODS

Zines were trialled as a reflective tool to support STEAM learning between November 2019 and February 2020 within the context of Science Gallery Dublin's OPEN MIND Studio, a week-long informal STEAM learning program for students aged 15–16 years old (Hurley, 2019). More than 130 young people were introduced to zine-making and supported to adopt the practice as a way to share their thoughts, feelings and experiences throughout their time at Science Gallery Dublin. Within this trial, zine-making occurred at the end of each of the five days and lasted between 40 min and 1 h. Through an iterative approach based on learner and facilitator feedback, the zine-making sessions were refined and adjusted. The details of each stage are presented in more detail below, to provide guidance for practitioners wishing to adopt this methodology in their own settings.

Step 1: Introducing Learners, to Zines and Zine Culture

By introducing learners to zine history and culture, they are grounded in an understanding that zines are first and foremost about self-expression, identity work, and exploring ideas, and communities of knowledge. Sharing choice examples of relevant zines The Burgundy Zine, (2021); Wang, (2021) can help learners to see that this is an exercise for them to own, customise and play with, as many have done before them. This is a stark distinction to other forms of evaluation such as surveys, which seek answers to specific questions. Instead, zine-making is grounded in what learners themselves wish to contribute (their own creativity, reflection) and take away (their zine, participation in and appreciation of a larger zine community) from the process.

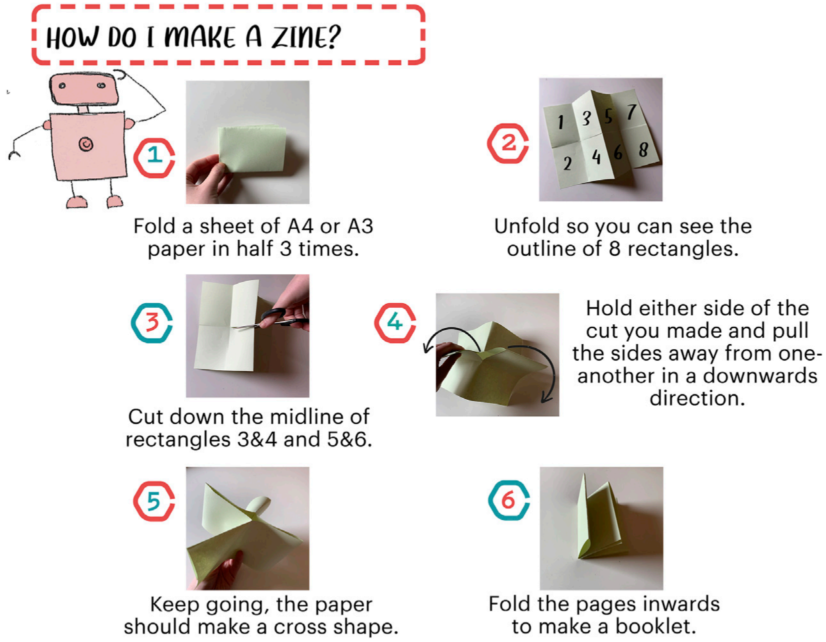

FIGURE 3 | Folding instructions for creating a zine.

Step 2: Folding the Zine

There are a number of zine binding methods, but the authors suggest the simple folding method, demonstrated in **Figure 3** below. This method involves making a "pocket zine" the result of folding a piece of A4 paper in half, three times.

Step 3: Prompting Science, Technology, Engineering, Arts, and Mathematics PedagogyEpistemic Practices: Exploration, Meaning-Making, Critique and Reflection

Though zines lend themselves to a combination of visual and textual communication, learners were made aware that they could choose one, the other, or both of these methods. Scaffolding the process of reflection with more structure was necessary in order to meaningfully support the learning experience. A series of prompts were refined, informed by the questions listed in *Zines as a Science, Technology, Engineering, Arts, and Mathematics Pedagogy*. The topic or concept can be replaced depending on the setting.

The prompts used to scaffold the zine reflections are as follows:

1. What do you wish people knew about [topic/concept explored during workshop]?
2. Is this topic related to anything you have learned in school or elsewhere? If so, how?
3. What are the impacts of [topic/concept]?
4. Did anything about this workshop surprise you? If so, what?
5. Make any final edits to your zine and prepare to share with the group

Step 4: Developing a Reflective Environment.

While introducing zines, folding them, and introducing the prompt questions go some way to developing a reflective atmosphere within the learning space, facilitators are advised to further this atmosphere by experimenting with the room layout, noise levels, and their own experience within their unique non-formal learning environment to explore what works most to support learner reflection. Learners were never advised not to speak, but often fell into quietude during the zine making sessions. Developing the appropriate atmosphere in the room will necessarily vary from group to group, and facilitators must be reflexive and respond to the groups' needs.

Step 5-Sharing their zine

Learners are invited to share their zines and to explain the motivations behind the topics they covered and the creative decisions they made. This encourages learners to clarify their visions and provides an opportunity for further reflection through dialogue (Knobel and Lankshear, 2002). This step is optional, but the community building potential of sharing zines and finding like-minded peers who share similar positionalities, values, and experiences has been a major benefit of the medium across the five testing locations.

Step 6-Evaluate Outcomes

Practitioners choosing to implement this zine method within an out-of-school learning environment may use the Ryan and Ryan (2015) 4Rs evaluation framework (**Figure 2**) to support their evaluation of the zines created.

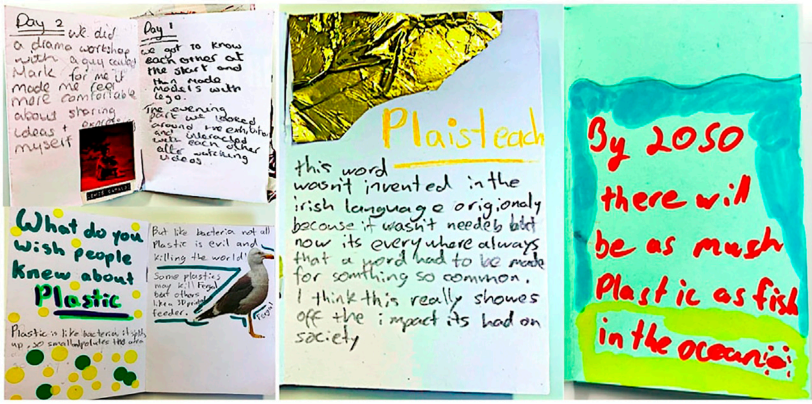

FIGURE 4 | A sample of zine pages created during STEAM workshops at Science Gallery Dublin.

Sample pages from zines created at Science Gallery Dublin can be seen in **Figure 4**. These zines were created during the initial development period of the tool and provided a kind of pedagogical and methodological blueprint to be followed by the institutions discussed in *Learning Environments*. These zines were created during a STEAM workshop series which covered topics related to conservation, sustainability, and the proliferation of plastic. Examples of each of the 4Rs shown in **Figure 2** (reporting/responding, relating, reasoning, and reconstructing) are identified in the zines shown in **Figure 4**, and discussed briefly below.

Reporting/responding: In the sample image at the top left of **Figure 4**, a learner first reports on their experiences during the first day of the workshops stating, "We got to know each other at the start and then made models with Lego..." On day 2 the learner takes their reflection a step further sharing how the experience made them feel, "We did a drama workshop with a guy called Mark. For me, it made me feel more comfortable about sharing ideas + expressing myself." It is also interesting to note that the learner chose not to respond to the prompts but felt comfortable to take ownership of the medium to document what was most meaningful to them.

Relating: In the image on the bottom left of the figure, another learner chose to write one of the prompts into their zine and responded by drawing a comparison between their understanding of bacteria and plastic. The learner also created a kind of character based on an image cut from a magazine, "Fergal" a seagull. The learner goes on to state in written text that like bacteria "not all plastic is evil..." and provides a brief example of how the character might benefit from an item made of plastic.

Reasoning: In the center image beneath a triangle of gold leaf, a learner shares their reflections on plastic's impacts on the Irish language. While the workshops focused on the proliferation of plastic as a material and its impacts on health, wellbeing and the environment, this learner chose to reflect on how it had changed their language and further how this could be considered evidence for its broader impacts on society.

Reconstructing: In the sample image on the right in **Figure 4**, another learner describes a not-so-distant future in which plastic particles outnumber the fish in the ocean. The text is framed by blue waves and underscored by yellow sand both drawn in marker. This prediction or hypothesis builds on the environmental interventions and challenges explored during the workshops and provides another example of a learner which chose to go beyond the prompts to imagining a possible future.

FACILITATOR FEEDBACK AND REFLECTIONS

Having finalised the above method through trials at Science Gallery Dublin, facilitators and program managers from Ars Electronica, LATRA, Kersnikova and Waag put the process into practice in their own institutions. They then reflected on the experience, noting the ways in which learners and workshop organisers navigated the process. These reflections have helped to identify the strengths, weaknesses and recommendations associated with using this tool, which are shared below.

Participants in the sessions which lasted between 45 and 60 min reported the highest level of enjoyment during the zine making process.

Facilitators also noted that zines provided a chance for learners to find a personalised way of communicating complex thoughts and ideas through text or image or some combination of the two. They also provided more introverted students an opportunity to express and share their reactions to a learning experience. This creative freedom allowed for non-traditional explorations of material and opportunities for learners to connect with subject matter in novel ways, demonstrating multiple literacies and providing practitioners with a deeper understanding of the ways each participant was relating to the workshops. It also created unique opportunities for further dialogue between participants and facilitators exploring the multiplicity of meaning which emerged from the reflective practice.

Further feedback suggested that the zines presented a chance for learners to take more active ownership of the learning process in choosing which moments to document, critique, and respond to, within this material object that they had created. These are artifacts which by design, belong to the learner, not to the facilitator, institution, or researchers-situating the learner explicitly in a seat of creative power and knowledge-making. Many learners wished to keep their zines following the learning experience. In some instances, it was reported that in addition to providing a personal record and response to a learning opportunity, the completion of the zine-making process offered some learners a sense of achievement and closure to the experience.

As both a visual and text-based artifact, the zine as a reflective tool it is capable of capturing broad responses to learning experiences which blur disciplinary boundaries (Congdon and Blandy, 2005). By their nature, zines can be adapted to multiple learning environments and learner needs. Requiring only pen and paper as material resources, learners are able to document and reflect deeply on learning experiences in a small booklet of their own design. As an alternative form of media with roots in DIY culture, zines have evolved an amateurish aesthetic which places primacy on the personal experiences and interpretations of the zine creator. In the feedback shared from both learners and facilitators, this has worked to minimize anxieties around social and academic resources.

In some cases, the openness of the medium became a source of creative anxiety. Some learners at times felt frustration with the process, with one facilitator reporting that learners at their institution felt their drawings were “ugly”, while others expressed feeling rushed while creating their zines. In some instances, learners expressed confusion over the lack of parameters inherent in the activity. In order to mitigate some of these frustrations and creative anxieties, some facilitators chose to use colored paper as opposed to white paper which resulted in a more relaxed attitude toward drawing and collage. Framing the prompts as provocations and inspiration for the zine-making process also served to address some challenges regarding the open-ended nature of the task. Some also played music during the sessions to support a more relaxed and reflective atmosphere. One of the most common challenges across all locations was the amount of time required for zine-making. Once learners became comfortable with the medium, many of them felt there was not ample time to fulfill their vision for their own zine.

DISCUSSION AND CONCLUSION

Zines allow a new kind of dialogue to take place between learners, educators, and institutions. Reflective zines encourage their makers to remix, re-present, and reimagine science and STEAM learnings in ways which position the maker as the knowledge creator and expert. Many of the organisations involved in the trial of this approach have chosen to continue to adapt and apply it in further programming, citing its enjoyable and empowering nature in giving voice to all learners especially those who are part of marginalized communities.

As outlined in the previous section, a lack of structure and parameters may be a barrier for some learners including those who are unfamiliar with reflective practice or zines. While the medium is meant to allow for creative freedom, some structure is needed to provide further support for reflective thinking. With the addition of the prompts, learners often provided reflections which reasoned through and reconstructed science and STEAM learning activities. The prompts provided learners with inspiration but allowed for enough personal freedom and choice to decide what they felt was most important to document.

The facilitators, researchers, and practitioners shared a number of key takeaways from their experiences utilising zines as reflective tools across informal STEAM learning settings:

1. Support learner creativity. Be clear that there is no right or wrong way to make a zine. This should be repeated throughout the zine sessions to mitigate creative anxieties and to instil that experience is about reflection and taking ownership of knowledge.
2. Remind the learners that this object belongs to them. Its value and purpose is entirely up to the learner.
3. Provide ample time. When learners are allowed to sink into the zine making process their reflections become more detailed and the experience is more enjoyable for them.
4. Create a reflective atmosphere. Playing music, even letting the learners choose the music can be an effective way of creating a relaxed space
5. Be flexible. Some learners will need more exposition while others will dive right in. Having examples of zines on hand is a helpful way to alleviate any uncertainties caused by the openness of the medium.

Reflective approaches for cultural institutions are more important than ever given the COVID-19 pandemic, racial reckoning, and continued global political and economic uncertainty, meaning that now is “the moment to act with humility and courage, to reform our approaches, and become cultural institutions which welcome, support, and value all communities” (Brown et al., 2020). Zines offer an inclusive and emancipatory opening to inter-and transdisciplinary thinking and the testing of ideas. They can act as a model or path into public participation on any number of subjects. It is a DIY medium where creators are able to dissect and reconfigure topics of interest and experiment with new ideas, hypotheses, and information (Congdon and Blandy, 2003). Zines encourage learners to relate their personal experiences, identities and values to STEAM subjects and to explore fresh connections to similar topics touched upon in more formal learning environments and in their day to day lives.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Trinity College Dublin research ethics committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AB led the conceptual design of this manuscript. AB, SP, MH, and JR wrote the initial drafts collaboratively. AB and SP co-led the research intervention in the field while MH designed and coordinated the research project within which this work was realised. All authors reviewed the manuscript and provided comments and feedback.

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Sediments and Seashores - A Case Study of Local Citizen Science Contributing to Student Learning and Environmental Citizenship

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Citizen science aims to bridge the gap between science and society by engaging people in understanding the process of science. This is needed to foster informed democratic involvement of critical, environmentally informed citizens. Can these aspirations be facilitated by school-based citizen science that offers opportunity to engage scientifically with environmental issues at a scale with local relevance? This is tested through application of Marine Metre Squared (Mm^2), a citizen science initiative for long-term monitoring of the New Zealand intertidal zone. Through direct observation and "hands-on" engagement, participants are involved in place-based learning that connects them with nature. Strong interest from teachers and uptake into school programmes has been key to its success in collecting long term biodiversity data. Through facilitated delivery, the project also has the capacity to meet school curriculum goals and develop the environmental science citizenship capabilities of participants. Assessing the use of Mm^2 as a citizen science intervention within schools, we found that it affected science learning, skill development and environmental attitudes. Our findings further demonstrate the effect of extended involvement in a citizen science project, the value of a local issue-focused project for student learning outside the classroom, and how school science education can be enriched through citizen science to also grow civic responsibility for the environment (environmental citizenship).

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INTRODUCTION

In a rapidly changing world, where pubic understanding and application of science is gaining in importance, a diverse range of approaches are being used by both scientific and educational organizations to move beyond traditional science learning environments (Bonney et al., 2009a; Falk and Dierking, 2002). Citizen science (CS), where the public participates in science research, is one such field of informal science education (Bonney et al., 2009b; Conrad and Hilchey, 2011; Pocock et al., 2017). Key to the value of these informal science experiences is the opportunity for the participants to engage in a hands-on, interactive way, and in subject matter that is directly relevant to their lives and interests (Falk and Dierking, 2010). Specifically, active first hand experiences, within the context of interest-driven projects, have been shown to link science learning to creativity and investigation (Bevan, 2017), increase understanding of key STEM practices, such as experimental design (Osborne, 2014), provide interactions with science professionals that inspire future career pathways (Ayar, 2015) and develop place-based environmental values (Thomashow, 2001).

Assessing the Outcomes of CS as Informal Science Learning

Informal science education and CS strive to foster a culture of excitement about science and increase participant knowledge about an aspect of science, but CS carries a specific aim to give participants an opportunity to actively apply science inquiry skills in novel research (Stylinski et al., 2020). Many CS projects target a narrow skill set, centered on data collection, as might be expected when a project is driven by scientists aiming to generate data and ensure its reliability and robustness (Gray et al., 2017). Thus, the development of CS projects is usually driven by a specific research question ahead of its goals for science education (Bonney et al., 2009a). Despite the prevailing scientific goals of CS to generate quality data (Bonney et al., 2009b), there is increasing focus on understanding the effect of CS projects on the participants themselves and on society (Bela et al., 2016; Kieslinger et al., 2018; Schaefer et al., 2021). With more science organizations and funding agencies investing in CS, evidence of its wider effects is needed to demonstrate the value of CS projects to society, as well as science. Within such evaluation, it is useful to discriminate between immediate and long-term effects.

Within one model of outcomes-based evaluation for CS, outcomes are considered the effects of outputs on a target group, and often measured through pre and post questionnaires (Kieslinger et al., 2018). In contrast, impacts are the long-term changes brought about on a societal level, and measuring the persistence of such perceived change over time is more difficult. For assessing CS outcomes at the individual level, personal learning and development gains are key (e.g., did participants develop new knowledge or skills, increase understanding or attitudes about science). Personal gains (gains such as enjoyment, or other personal satisfaction from engaging) may further lead to change in attitudes or behaviors, as well as an increased sense of ownership and empowerment (Kieslinger et al., 2018). Based on previous work evaluating informal science education (Friedman et al., 2008; Bonney et al., 2009a), a framework was developed by Philips et al. (2019) to describe the learning outcomes from participating in CS. Six learning outcomes were identified including: interest in science and the environment, self-efficacy for science and the environment; motivation for science and the environment; knowledge of science content and the Nature of Science; skills of science inquiry; behaviour and stewardship. However, few CS projects evaluate these outcomes for individual participants, and when they do, the most commonly assessed are an increased interest in science and learning new content knowledge (Bela et al., 2016); only rarely are science inquiry skills assessed (Phillips et al., 2018). Indeed, although CS projects might be particularly interested in assessment of skills with the goal to improve training for data quality, a wide review by Stylinski et al. (2020) found that few projects conduct any kind of robust science skills assessment. Even fewer CS projects assess personal outcomes around a sense of achievement or awareness of interests or values (e.g., Groulx et al., 2017; Phillips et al., 2018) despite the fact that this kind of engagement can contribute to civic action as well as democratization of science (Brossard et al., 2005; Boland, 2011; Herr and Anderson, 2014; Phillips et al., 2018).

However, it is increasingly observed that CS can connect participants to nature in ways that foster change in environmental attitudes (Brossard et al., 2005; Crall et al., 2013; Toomey and Domroese, 2013), and pro-environmental behavior (Heimlich and Ardoin, 2008). Such behaviour change may be brought about by increased awareness of local biodiversity from observation and data collection (Cosquer et al., 2012; Toomey and Domroese, 2013; Johnson et al., 2014; Forrester et al., 2017; Schuttler et al., 2019). It may also arise from emotional connections with nature that are developed through direct experience with the natural world and leads to feelings of responsibility and stewardship (Nisbet et al., 2009; Wals et al., 2014).

Changes in attitude and behavior are critical for addressing a diversity of global environmental problems requiring community-level responsibility (Valencia Sáiz, 2005; Ballard et al., 2017b). In order for CS to promote such environmental citizenship, projects need to build a sense of collaboration and communal responsibility for the environment through place-based situated learning that helps participants make connections between the data they collect and larger environmental problems (Jørgensen and Jørgensen, 2020). This makes it especially important to involve youth, who are still actively forming their values and connections with nature (Haywood, 2016), such that youth inclusive CS projects may generate long lasting impacts (Schuttler et al., 2019). Most assessment of the educational effects of CS have focussed on outcomes for adults. Although many CS projects involve youth (often through schools) only a handful have assessed the effect on these participants. Again, most studies focus on content knowledge that is project specific, with most showing improvement (Zárybnická et al., 2017), although not all (Vitone et al., 2016). One recent study (Lewis and Carson, 2021) showed improvement in science skills, using a retrospective pre and post-test, and other studies showed the value of a CS project for building capacity for environmental agency and conservation action (Bela et al., 2016; Ballard et al., 2017a; Harris et al., 2020). More positive attitudes towards science (Vitone et al., 2016; Doyle et al., 2019) and increased engagement with nature (Schuttler et al., 2019) are also observed, although not specifically measured.

Enhancing Collaboration Between CS and Formal Science Education

Globally, the collaboration between CS and formal science education remains underexplored, with many CS activities still focused only on data collection (Shah and Martinez, 2016; Turrini et al., 2018; Nistor et al., 2019). However, providing opportunities for students to engage in multiple stages of the science process, including data analysis and interpretation, is a powerful way to develop science inquiry skills (Lewis and Carson, 2021). In addition, working on projects that are relevant to their local environment is increasingly recognized as a powerful way to spark curiosity and interest in science, develop understanding of the science, engage positively with nature, and provide opportunity to apply science skills (Trumbull et al., 2000; Bonney et al., 2016; Zárybnická et al., 2017; Schuttler et al., 2019; Blewitt, 2020). Furthermore, place-based experience encourages stewardship and environmental action (Cooper et al., 2007; Lewandowski and Oberhauser, 2017; McKinley et al., 2017). Indeed, it may produce multiple synergistic outcomes such as understanding of the connections existing between science, place, ecosystem, and the impacts of one's actions on the environment. Such synthesis has been referred to as "environmental science agency," where youth gain knowledge and skills in environmental science, identify their own interest and expertise in this area and use that expertise and CS practices as a foundation for change (Ballard et al., 2017a). Key factors found to influenced the development of environmental science agency include the time youth spend participating in the program, their relationship to place and the authentic nature of the science. Based on these observations, Ballard et al. (2017a) recommend that CS programs should provide opportunities for youth to engage in rigorous data collection and analysis, share their findings with relevant public and scientific audiences, and, understand ways that they can take action to improve the health and resilience of the ecosystem.

The synergies between science education, environmental education and informal science education, including CS, are being realized through "whole school approaches" with local curriculum. These are increasingly developed in eco- or enviro-school models, where inquiry-based learning strengthens community involvement and develops a sense of place (Wals et al., 2014; Eames and Mardon, 2020). Working with whole classes (rather than individual students who self-select to participate in CS) provides the opportunity to engage with diverse participants (e.g., a range of ethnicities, socio-economic backgrounds and academic ability) and furthers the wider aim of growing civic engagement (Paige et al., 2016).

A New Zealand Case Study in Embedding CS in Formal Science Education

A case study of the effects of embedding CS within school programs is explored here, within the context of the New Zealand (NZ) education system. The CS movement gained rapid traction in NZ when the government released their strategic plan for science in society (New Zealand Government, 2014). The overarching goal was "participatory science," which aims to enhance teaching and learning, and to engage the wider community with science and authentic research in order to increase public understanding of science and technology. These goals were deemed key for informed democratic involvement and to bridge the gap between science and society.

The vision of the New Zealand Curriculum (2007) is for young people to become confident, connected, actively involved, lifelong learners. Students are encouraged to value "community and participation for the common good" (page 8), which is associated with ideals such as peace, citizenship, and manaakitanga (hospitality/kindness). The curriculum also emphasizes that students need opportunities to develop their capability as users of knowledge and skills in wide-ranging contexts, now and in the future. The national framework of "science capabilities for citizenship" (Hipkins and Bull, 2015) highlights the need for students to have the skills to critically engage in science and be ready, willing and able to use their science knowledge in real life scenarios. School-based CS would appear to be an ideal avenue for schools to meet the stated curriculum goals of student able to "use their science skills to participate as critical, informed and responsible citizens" (Ministry of Education, 2007, page 17).

The case study presented here focuses on the effects of a nation-wide CS project, Marine Metre Squared (Mm^2), aiming for long-term monitoring of the NZ intertidal zone. It involves monitoring the biodiversity, distribution and abundance of intertidal species across time through the use of quadrat surveys and on-line data archive and analysis platform (www.mm2.net.nz). Participants upload their data to a searchable database and learn to analyze and interpret their data in context of others. Enabling participants to review the results of their initial surveys aims to facilitate their asking of questions about environmental issues relevant to their region, which they can investigate by carrying out further surveys. Such prolonged engagement ultimately can lead to improved understanding of coastal processes and environmental management. Thus, the study presented here investigates the effects of implementing CS as an intervention within formal science education to enhance student learning, science skills and environmental citizenship capabilities. It specifically examines how several schools used Mm^2 to assess the impact of increased dredging in their local harbour on the rocky intertidal marine community (referred to hereafter as the Sediment and Seashores project).

METHODS

Implementation of Mm^2 Interventions

The effects of implementing Mm^2 with school classes was assessed over a period of 3 years. An adaptive design was used (McNiff, 2013) such that different elements of the study were adjusted between years as our learning about student interaction with the project evolved. Of particular note, both the duration of interaction and the marine science focus changed: initially Mm^2 was implemented as a short intervention for primary students to learn about local intertidal communities; in subsequent years it was applied as a tool for primary and secondary students to investigate a specific local issue (the impact of increased dredging on the rocky intertidal community of the Otago Harbour, the Sediment and Seashores Project). Learning from 1 year's evaluation informed the project design and evaluation in subsequent years, creating a cycle of practice-led action

TABLE 1 | Comparison of questionnaire methodology, intervention duration and participant experience from 2015 to 2017 for primary and secondary level students from multiple schools.

Year	Level	# Students (schools)	Prior experience	Intervention duration	Pre/Post questionnaire methodology
2015	Primary (Yr 4–6)	93 (2)	none	1 day	Pre A_1 → Post B_1 (half class) Pre B_1 → Post A_1 (half class)
2016	Primary (Yr 3–8)	142 (8)	none	6 months program	Pre A_2 → Post B_2 (half class) Pre B_2 → Post A_2 (half class)
2017	Primary (Yr 4–7)	92 (5)	37 students (40%) participated in 2016	6 months program (× 2 for 40%)	Pre A_3 + → Post A_3 + (+ additional questions specific to pre and post)
2016/17	Secondary (Yr 10–11)	56 (2)	none	6 months program	Pre A_4 + → Post A_4 + (+ additional questions specific to pre and post)

*Subscript markers for different questionnaires indicates where they included enough different questions between years to be considerd different questionnaires. Questionnaires were identical between years for secondary students (and thus years are pooled). All questionnaires are available in **Supplementary Table 1**.*

research (Herr and Anderson, 2014), in which iterative cycles of reflection adaptated the enacted program and associated evaluation responsively. Specifically, the project became more focused in its effort to coalese work around issues and opportunities for applied approaches.

Across all years, recruitment was implemented by a flyer that was emailed to all primary and secondary schools in the Dunedin city region, outlining the project objectives, activities and duration, and inviting classes to participate. Further discussion with interested teachers ensured that they were willing to complete the full project. Once their involvement was confirmed, a local intertidal location was assigned to their school, and field and classroom sessions were scheduled. The design for each of the 3 years' studies is described below.

The first intervention (2015) was the shortest: a 1-day Mm^2 field trip for 93 primary level students at two schools (**Table 1**). Working in small groups they conducted an intertidal survey followed by classroom-based data entry of their observations into the Mm^2 website, graphing and reviewing of their data to identify key findings, questions, concerns and next steps, which they presented as posters. A pre-questionnaire was administered by the teacher just prior to the Mm^2 survey day, and the post questionnaire was administered in the classroom at the end of the field trip day.

In the second year (2016), 142 primary and 30 secondary level students from multiple schools participated in the Sediments and Seashores Project, which involved six half-day sessions over a 6 month period (**Table 1**). The programme began with a 1 h classroom session to introduce the marine environment of Otago Harbour, highlight the environmental concerns associated with the increased bottom dredging to deepen the shipping channel, and propose the rocky intertidal as a habitat that could be impacted by increased levels of sediment in the water. Students then worked in small groups to develop a research plan that included articulating their research question and identifying suitable locations for their study, what they would need to measure and record, what equipment was required, when they should sample and who might be interested in their work and could provide support. The class as a whole then decided on the research methodology they would use. They made two field trips to a rocky intertidal site to complete 5 Mm^2 surveys along a 30 m transect at two tidal heights, also recording substrate type to further assess habitat. Data analysis and summary was the same as described for the first year but also included students writing blog posts about their experience. After the second field trip, students compared their data with their previous observations and also categorised sensitivities to sediment of the species surveyed (noting in particular those photosynthetic, sessile, slow moving and/or filter feeding). Final summary sessions involved comparing class data with different sites in Otago Harbour surveyed by other schools. At culmination of the project, representatives from the schools joined a community sharing session, with project leaders, local scientists, funders, Port Otago officials, parents and community members, in which each school presentated their findings, and a project leader presented a complete summary of the study. The pre- and post-questionnaires were administered in the classroom (at beginning of introductory session, and at end of the school summary session), and teachers also completed a short questionnaire at the end of the project.

In the third year (2017), 92 primary and 26 secondary level students from multiple schools participated and the same intervention methodology as the previous year was used. However, schools involved in previous years were encouraged continue their participation, so students' prior experience became another variable to consider in the evaluation (**Table 1**). Although primary students in 2015 and 2016, and secondary in 2016/17 had no previous experience with with Mm^2, in 2017 40% of primary students had experience through the 2016 Sediment and Seashores Project, essentially doubling the duration of their engagement, and providing an opportunity to look at the impact of longer term involvement. At secondary level, as the 2017 intervention methodology and the questionnaire (with the exception of a few additional questions) was not changed from 2016, the data were pooled as 2016/17.

Multiple topics were queried as part of routine education programme assessment of the New Zealand Marine Studies Centre (NZMSC), including prior experience, motivation, engagement with science/environment, science skills, knowledge and understanding of science/environment, attitudes and behaviours towards the environment, however only the last three are focused on here. All questionnaires are available in **Supplementary Table S1**. First names linked a student's pre and post responses, but no other identifying information was collected. The NZMSC is required to evaluate the effectiveness of its education program delivered to schools as part of its Ministry of Education contract to deliver learning experiences outside the classroom. Permission was sought from the schools and guardians for participation in the NZMSC programs. All data was imported into IBM SPSS Statistics for Macintosh, Verson 26.0 for analysis.

Attitudes were assessed via a Likert scale using a 1= low to 4 = high scale. When pre/post data were available, paired sample t-tests were used. When comparing different samples, independent sample *t*-tests were used. Although the Kolmogorov-Smirnov test showed that the data were not normally distributed, violations of normality with a sample size larger than 30 is not typically a problem (Ghasemi and Zahediasl, 2012). To be certain, all Likert-scale questions were re-analyzed using the Mann–Whitney U Test and Wilcoxon Signed Rank Test, and the results were not different from the parametric results. Questions answered by free text response were coded into categories of concepts that emerged from the data, using a grounded theory approach (Sbaraini et al., 2011). All open-ended responses were coded by two independent coders; when discrepancies occurred, the coders discussed until consensus was reached. For each category only two response options were possible (category identified = 1, or category not identified = 0). If the same category emerged more than once in the text response, it was only recorded once. These questions were analyzed using non-parametric measures including Chi Squared Test (when the question was asked of different groups of participants pre and post). Related Samples McNemar's Test (repeated measures design) was used when the question was asked of the same group of participants at time 1 (prior to the intervention) and time 2 (post intervention), both variables were categorical with only two response options. In the third year, primary students with previous experience with the project were compared with those without prior experience using a two-way repeated measures ANOVA.

RESULTS AND DISCUSSION

Findings from across the years of implementing Mm^2 as a CS intervention with primary and secondary students are integrated here as they relate to four different outcomes: student interest in learning, their science skills and their marine species knowledge, and their attitudes and behaviours towards care for the environment. Adaptive learning across the years of project implementation is also discussed as it relates to the potential for embedding CS interventions in schools.

Interest in Learning

The effect of a CS intervention on student interest in learning was assessed from different perspectives. This included student interest and enjoyment of the Mm^2 project and/or Sediment and Seashores Project specifically, as well as their interest in learning about the marine environment more generally.

As a starting point, primary students (2016) selected from a list the aspects of the Mm^2 project they were most interested in, and pre-intervention chose most frequently: *exploring the seashore* (78%), *being outside* (47%), *learning new skills* (41%), and *getting wet and dirty* (39%) (**Figure 1**). Dominance of these interests remained the same post-intervention, with exception of slightly more interest in *getting wet and dirty*. The only statistically significant change was a decrease in interest in *meeting scientists* (**Figure 1**), which may be linked with students feeling they had already met the scientists involved. Secondary students were asked a similar question but answered it by free text responses in a post questionnaire. Similar to the primary students, they expressed most enjoyment in *learning about the marine environment* (73%) and the *field trip experience* (32%), with some enjoyment also of *interaction with classmates* (7%) and *helping marine life* (5%). Like other CS projects (Cosquer, Raymond et al., 2012; Toomey and Domroese 2013; Schuttler et al., 2019), this intervention clearly provided a pleasurable opportunity to connect with nature, facilitated here through hands-on identification and counting of intertidal species within the survey area. Student interest in learning about the marine environment was also queried using a Likert scale (2016). This revealed a high interest level for primary students both pre and post intervention, with average scores greater than 3, although there was a significant decrease pre - post ($\bar{x} = 3.42 \pm 0.81$, $\bar{x} = 3.10 \pm 0.87$, $t(88) = 3.75$, $p < 0.001$). Among secondary students, interest was also fairly high (average scores greater than 2.6), with no significant change noted from pre—post.

Although students were clearly interested in learning more about the marine environment at the beginning of the intervention, most would have had little understanding of what that would involve. The fact that the Mm^2 surveys entailed close observation and detailed reporting, often under cold, wet conditions, may not have met the expectations of all students. Secondary students were probably more aware of what a "science field trip" might involve, which may explain why their average interest level was maintained throughout the study. Interest levels had been anticipated to increase with exposure to field work in the marine environment, however, it may also be that by the end of the 6-month project, students felt they had a good understanding of this environment and were ready to move on to a new topic. It is also of note here, and throughout this study, that other CS projects assessing effects of participation, generally involved self-motivated volunteers (Schuttler et al., 2019). As these volunteers already often have a positive attitude toward the topic in the first place, no noticeable change is detected as a result of participation (Forrester et al., 2017). Further consideration of the drivers of these patterns is warranted as other studies have shown that nature-based learning can be expected to have many positive impacts on learning, including intrinsic motivation, which plays a role in engagement and longevity of interest in learning (Hobbs, 2015; Kuo et al., 2019). It is possible that using a retrospective pre-test might have yielded different results; Vitone et al. (2016) noted that opinions can be ranked differently in retrospective pre-test compared to actual pre-tests.

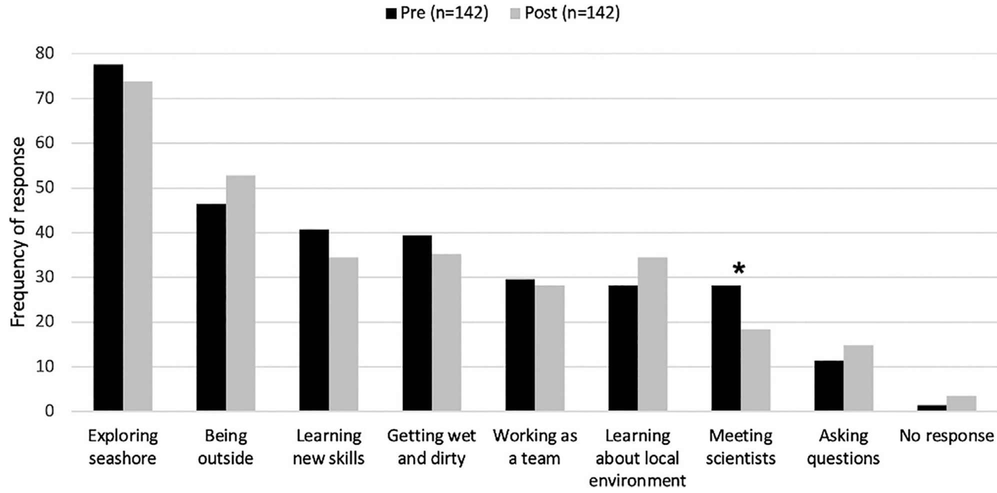

FIGURE 1 | Aspects of interest to primary students in 2016 Seashore and Sediments Project. Significance* of Meeting scientist response $p = 0.45$, $n = 142$, McNemar's Test).

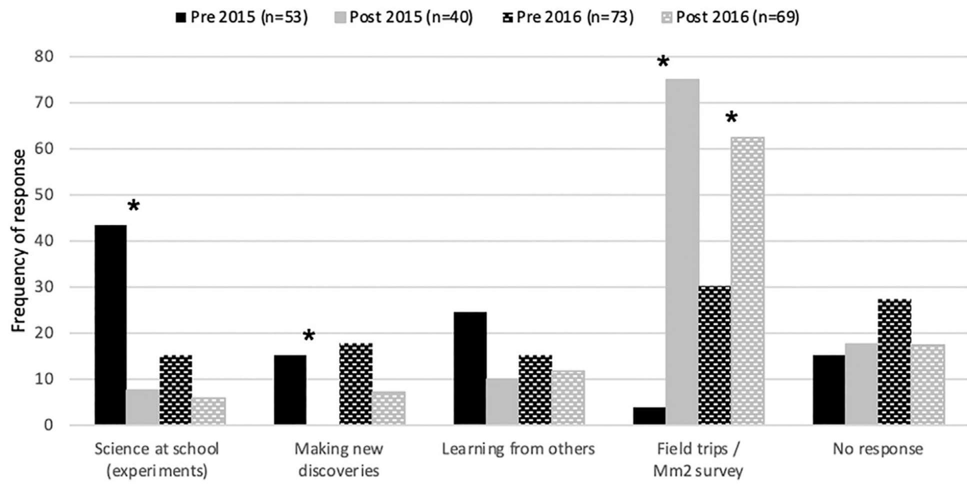

FIGURE 2 | Categories of response from primary students' description of "when they felt they were acting as a scientist" (2016, 2017). Pre - post responses compared with chi square test for independence with Yates' Continuity Correction. *Significant differences pre - post in 2015: doing science at school (χ^2 (1, $n = 93$) = 12.86, $p < 0.001$, phi = −0.396); field trips/Mm2 survey (χ^2 (1, $n = 142$) = 48.134, $p < 0.001$, phi = 0742); making new discoveries (χ^2 (1, $n = 93$) = 0.028, $p = 0.028$, phi = −0.267). In 2016: field trips/Mm2 survey (χ^2 (1, $n = 142$) = 13.53, $p < 0.001$, phi = 0.323).

Development of Science Skills

The effect of a CS intervention on student understanding of the process of science and development of science skills was assessed by asking them about their experience doing science, as well as their attitudes towards being a scientist. Scientists are often described as having a particular skill set so students were also asked to describe their own perceived skills to ascertain the extent of overlap of these skill sets. Finally, students were asked to rate their confidence in carrying out different stages of the scientific process.

Primary students were asked to describe a time when they felt they were acting like a scientist. Although some students identified as many as three different occasions, many were not able to name one. There was no significant change pre-post in the number of occasions this was observed, in either year the question was asked. Four themes emerged from student responses: *during experiments in school, when making new discoveries, when learning from others,* and *during field trips* (**Figure 2**). Field trips such as the Mm^2 survey became more closely linked to students feeling like they were acting as scientists in 2015; where the dominant response pre-intervention indicated doing *experiments in school* (43%), and post-intervention the majority (75%) indicated the *field trips/Mm^2 survey*. This is likely due to the fact that they completed the post survey on

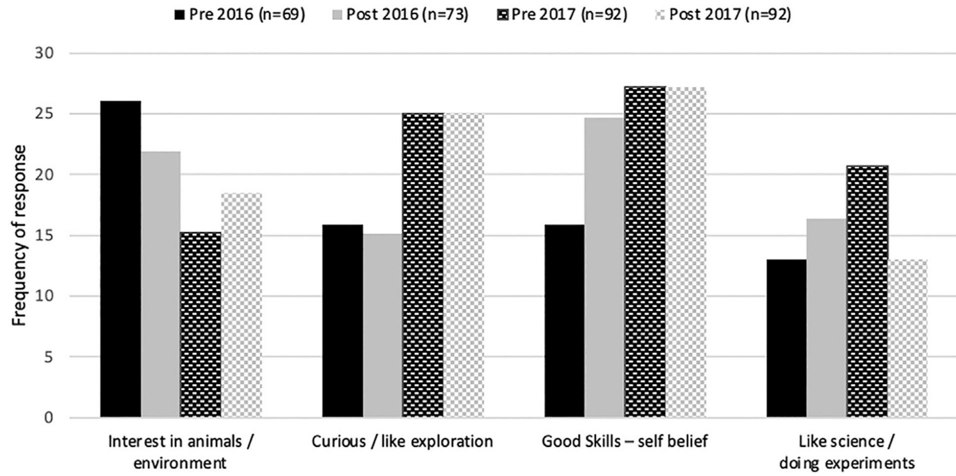

FIGURE 3 | Categories of response from primary students asked "why they would make a good scientist." (A "no response" category (not shown) was low pre - post in 2016 and 2017 (5.8–0% and 4.3–2.2%, respectively).

the same day as the Mm^2 field trip. There was both a significant pre—post decrease in the number of students identifying *doing science at school* and increase in identifying *field trips/Mm^2 survey* (**Figure 2**). In 2016, a similar pattern was observed with the number of students that identified *field trips/Mm^2* increasing significantly pre - post (from 30 to 62%, **Figure 2**).

To further interrogate their understanding of their own skills and abilities for the process of science, primary students were asked (2016 and 2017) if they thought they would make a good scientist and the majority responded affirmatively in both years. However, although it was hoped that affirmations would increase pre—post intervention, the reverse was true (2016 pre-post $\overline{x} = 0.61 \pm 0.492$, $\overline{x} = 0.53 \pm 0.502$; 2017 pre-post $\overline{x} = 0.73 \pm 0.48$, $\overline{x} = 0.56 \pm 0.50$, which was significant: $t(84) = 3.31$, $p < 0.001$). Although the objective of the CS intervention was not necessarily to upskill students for a science career, it did aim to provide an opportunity to engage in authentic science research. Students clearly perceived doing a Mm^2 survey as doing science, but this did not necessarily affect an immediate increase in their confidence that they would make a good scientist.

When asked to explain, in a follow up question, why they felt they would or wouldn't make a good scientist, the primary themes emerging from affirmative responses included: *an interest in animals/environment*, *enjoy doing science at school (e.g., experiments)*, *curiosity/like exploring*, *have good skills/self-belief* (**Figure 3**). There was no significant change pre - post and these categories of response emerged consistently across years, with small variations in frequency of responses. In 2017 students gave multiple reasons more often than in 2016, and this may be explained by the fact that 40% had had prior experience with the project (however there was no significant change pre – post). *Interest in animals/environment* was dominant in 2016. In contrast, in 2017, *curious/like exploration* and *good skills/self-belief* were dominant responses, possibly linked with the greater proportion of students with prior experience. The students who did not think they would make good scientists were less able to articulate reasons for their decision. Two themes emerged: *limited skill/experience* and *limited interest* (**Figure 4**). This pattern was observed across years with no significant change pre – post.

A question assessing skills that the students felt they had, compared pre – post, gave further indication of the intervention's impact. Primary students were asked to select all the personal skills they felt they had from a list of nine options, some chosen to represent skills typically associated with doing science (e.g., *observant, investigative, curious, numerical*), some less associated with doing science (e.g., *sporty, funny*) and some desirable for many careers (e.g., *creative, passionate, organised*). Every skill was reported by some students in every year, although relatively fewer were selected in 2015 (**Figure 5**). *Creativity* scored highest every year, reported by over 60% of students (pre and post), with its maximum frequency in 2017 (85–87% pre - post). *Curious* was also dominant in 2016 and 2017 (54–63%, 62–65% pre – post, respectively). There were no decreases in any perceived skills across years, although several increased in frequency including *numerical* and *creative*. *Numerical* also had its highest frequency in 2017 (at 42–37% pre-post). When pre – post interventions were specifically compared, only *observant* and *investigative* skills increased across all years (and approached significance). These results give some suggestion of an increase in perceived science-linked skills, although the only skill to show any significant change pre -post was *passionate* (2017, **Figure 5C**).

Investigation of the effect of the CS intervention on science skills was also approached through questions specifically about Mm^2. Primary students in 2015 were asked why it was useful to count the marine plants and animals in a metre squared area, and five themes emerged from their free text answers: *data on species/habitats, data on population size/change, data on seashore health, care for plants and animals,* and *learning experiences*, with the first two given most frequently (**Figure 6**). Pre-intervention the majority of students knew that they were collecting data on species and habitats, but very few understand its relevance to

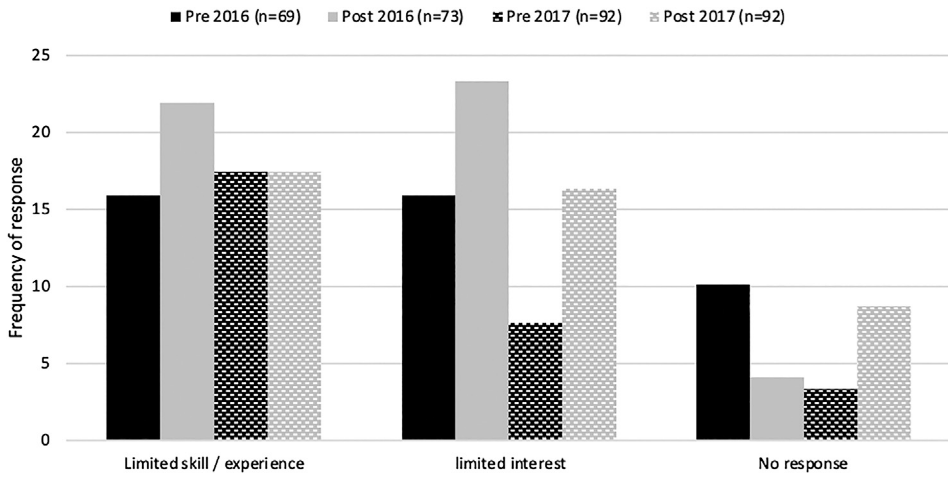

FIGURE 4 | Categories of response from primary students asked "why they would not make a good scientist". A near-significant difference pre - post limited interest was found in 2017 (7.6 vs. 16.4%; p = 0.057, McNemar's test).

monitoring population size and change until after the intervention (a significant change, **Figure 6**). Less that 8% of the students connected the survey experience with assessing intertidal health and this did not change from pre - post. Although the proportion of students unable to answer the question decreased significantly (23–2%, **Figure 6**) there was still relatively limited awareness of the multiple functions of the Mm^2 survey methodolgy.

Assessing student confidence in science skills was also specifically queried in 2017. Primary students asked to rate their confidence in designing and carrying out an intertidal survey on a Likert scale, indicated relatively high levels of confidence in 2017 (although with no significant difference pre - post, $\bar{x}$ = 3.10 ± 0.92, $\bar{x}$ = 2.92 ± 0.87). Although it was anticipated that the intervention would increase confidence, in retrospect, the question wording may have been to blame as the skills of "designing" vs. "carrying out" are two distinct tasks and the students may not have felt as confident in both areas. When analyzed relative to a student's previous experience, no significant difference was found. However a positive relationship was suggested between experience and confidence by the fact that experienced students remained confident pre - post ($\bar{x}$ = 3.03 ± 0.94, $\bar{x}$ = 3.06 ± 0.89), whereas students without prior experience appeared to lose some confidence ($\bar{x}$ = 3.16 ± 0.90, $\bar{x}$ = 2.82 ± 0.84). This suggests that the experience of participating leant continuity to confidence, i.e. repeat participation in Mm^2 may contribute to longer term skills confidence.

Secondary students were asked more specifically to rate their confidence level in a range of skills involved in a Mm^2 survey. These included: *carrying out a science investigation, writing a hypothesis/research question, representing experimental results in different ways* and *reviewing work critically and connecting their science learning to current environmental issues.* Their reported confidence levels were also fairly high across years (means ranging from 2.6 to 3.1) and they either stayed the same or increased pre -post (**Table 2**). Although the increase was significant for only one skill, *carrying out a science investigation*, this was heartening, as it was the focus of the project. In a follow-up question asking them to identify what science skills they developed through participation in the project, the majority self-reported *survey methods* (55%), *data collection* (54%) and *data analysis* (54%). The lesser remaining responses included *species identification* (32%), *experimental design* (13%) and a range of other skills under 10% including: *use of scientific equipment*, *observation/knowledge*, *team work/personal skills* and *practical skills.*

Further validation of the effect of the intervention on enhancing science skills and knowledge came from the comments solicited from classroom teachers (18) at the conclusion of their class involvement in the project. All comments were positive, with only a few suggesting ways that the project could be extended. Primary teachers recognized its impact on students doing science, including student's increased understanding of the nature of science, how to do environmental surveys, and handle the data (e.g., entering data online and graphing). This is reflected in comments like: *"made the students realize science is not just about fizzing and foaming, science is about problem solving, forming questions, drawing conclusions," "strengthened and deepened Nature of Science understandings," "I was amazed how they coped with entering data on-line and working with different graphs. Also, they learn the value of measuring using the m^2."* At secondary level, teachers highlighted the skills of science thinking as well as the importance of civic engagement to applying learning to "real world" situations: *"great role modelling of science thinking," "making them aware of their role as citizen scientists, good environment/ecology application," "students got the chance to relate learning in ecology to real world, thinking about significance of sampling error and what the data means for the environment/species."* Student's application of their understanding of the environment and species was frequently mentioned. The positive impact of the intervention on teachers'

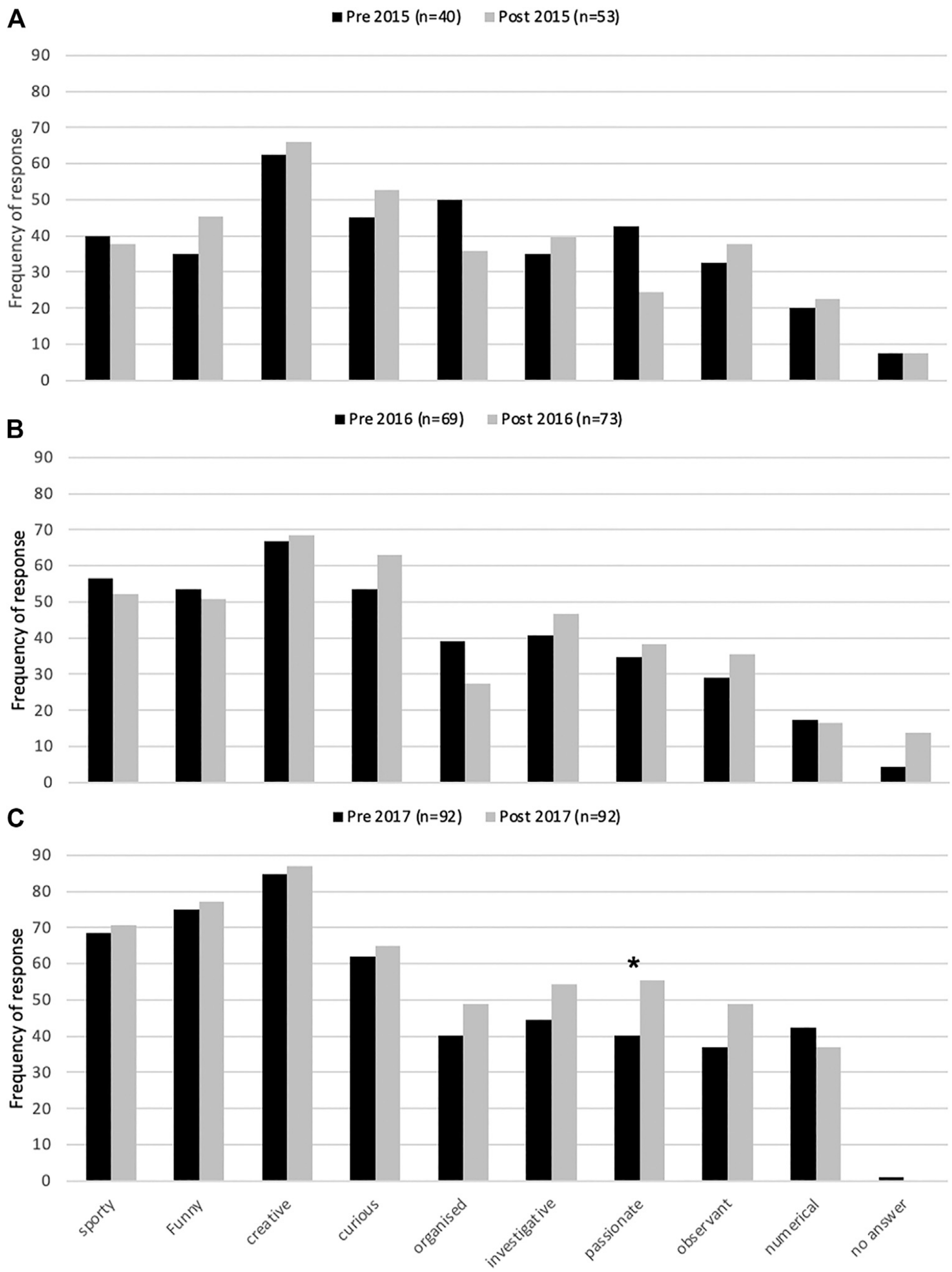

FIGURE 5 | Personal skills as identified by primary students across 3 years: **(A)** 2015, **(B)** 2016, **(C)** 2017. *Significant differences pre - post in 2017: passionate (40–55%, p = 0.018, McNemar's Test), observant (37–49%, p = 0.054) and investigative skills (45–54%, p = 0.093).

confidence and experience in science was also noted, as well as their appreciation of a structured activity for field trips with clear links to the Nature of Science strand in The New Zealand Curriculum (Ministry of Education, 2007). These positive effects on teachers and students mirror those found by Paige et al. (2016) who observed that both teachers and students found the collection and use of real data highly engaging, with teachers reporting increased confidence to plan and teach units of work that moved away from textbook-orientated approaches to science. Combined, these results support the idea of CS as valuable in formal education settings to teach science inquiry skills (Bates et al., 2015; Shah and Martinez, 2016; Saunders et al., 2018; Nistor et al., 2019). The limited involvement of CS in school programs may stem from CS project designers not including science learning outcomes as a clear goal, but it also may arise from teachers not understanding the potential value of CS for delivering curriculum objectives (Phillips et al., 2018).

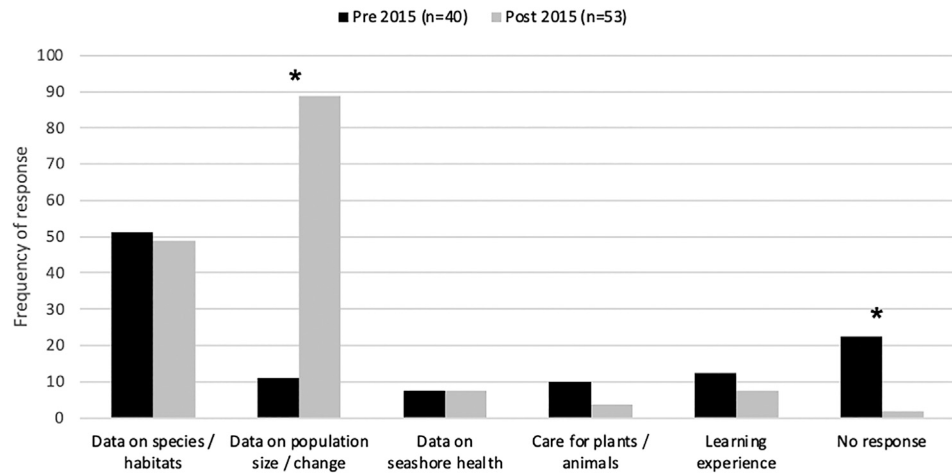

FIGURE 6 | Primary students' understanding of why it is valuable to count the animals and plants found in a metre squared area. *Significant difference pre - post for data on population size/change (11–89%, χ^2 (1, n = 93) = 14.014, p = 0.000, phi = −0.412, chi-squared test for independence with Yates' Continuity Correction), and no response (23–2%, χ^2 (1, n = 93) = 8.060, p = 0.005, phi = 0.329).

TABLE 2 | Secondary student confidence levels in their science skills pre and post intervention (2016/17, mean ± SD, significance evaluated with paired samples *t*-test).

Question	Pre	Post	T(n)	p
Confidence in carrying out a science investigation	2.59 ± 0.66	2.87 + 0.80	*t*(53) = 2.593	*p* = 0.012
Confidence in writing a hypothesis/research question	2.94 + 0.72	3.11 + 0.67	*t*(52) = −1.541	*p* = 0.129
Ability to represent experimental results in different ways and review work critically	2.67 + 0.70	2.67 + 0.67	*t*(53) = 0.000	*p* = 1.00
Ability to connect your science learning to current environmental issues	2.92 + 0.68	2.96 + 0.66	*t*(52) = −0.405	*p* = 0.687

TABLE 3 | Primary student scores for identification of different marine animals/plants (independent samples *t*-test (2015–2016) or paired samples *t*-test (2017) between pre – post intervention.).

Level of ID	Year	Pre M (SD)	Post M (SD)	T(*n*)	p
Animal/plant groups	2015	5.20 + 1.26	5.57 + 1.08	*t*(91) = 1.47	*p* = 0.137
Animal/plant groups	2016	5.72 + 0.68	5.95 + 0.33	*t*(140) = 2.43	*p* = 0.017
Crab/snail species	2015	2.91 + 1.66)	3.00 + 1.55	*t*(91) = −0.279	*p* = 0.781
Crab/snail species	2016	3.15 + 1.67	4.20 + 1.63	*t*(140) = −3.74	*p* < 0.001
Crab/snail species	2017	3.03 + 1.68	3.93 + 1.66	*t*(91) = −4.137	*p* < 0.001

Knowledge About Intertidal Species

Impact of the CS intervention was also assessed by interogating student's knowledge gain, specifically around their understanding of common marine plants and animals within their marine environment. Primary students were asked to match the name of an animal or plant (at either group or species level) with a drawing of it. One question (asked in first 2 years) tested students' abilities to distinguish between a crab, snail, mussel, barnacle, fish and seaweed. A more focused question (asked across all 3 years) tested their ability to distinguish between three different species each of crabs and snails. For both questions, responses ranged from 0 (no species identified correctly) to 6 (all species identified correctly) (**Table 3**). In all years, scores increased pre – post and, as might be expected, students scored higher in identifying at group level (means ranged from 5.20 to 5.95), than at species level (2.91 to 4.20). Duration of intervention appeared to correlate with identification skills. For the 1-day intervention there was no significant difference in pre - post ability to identify the organisms in either question, however, for the 6 month experience (2016) there was a significant increase for both questions pre - post (**Table 3**). The same was true for students in 2017 (asked just the second question). Further, those students with previous experience had significantly higher scores pre and post ($\bar{x}$ = 3.46 + 1.73, $\bar{x}$ = 4.30 + 1.47) than those without experience ($\bar{x}$ = 2.74 + 1.60 and $\bar{x}$ = 3.96 ± 1.74, F(1, 90) = 6.022, p = 0.016, partial eta squared = 0.063).

To investigate student's knowledge of the ecology of the intertidal zone, a further question (implemented across all years) prompted students with an image of an intertidal crab and asked them to list the challenges it had to deal with in its environment. Free text responses were thematically coded and a

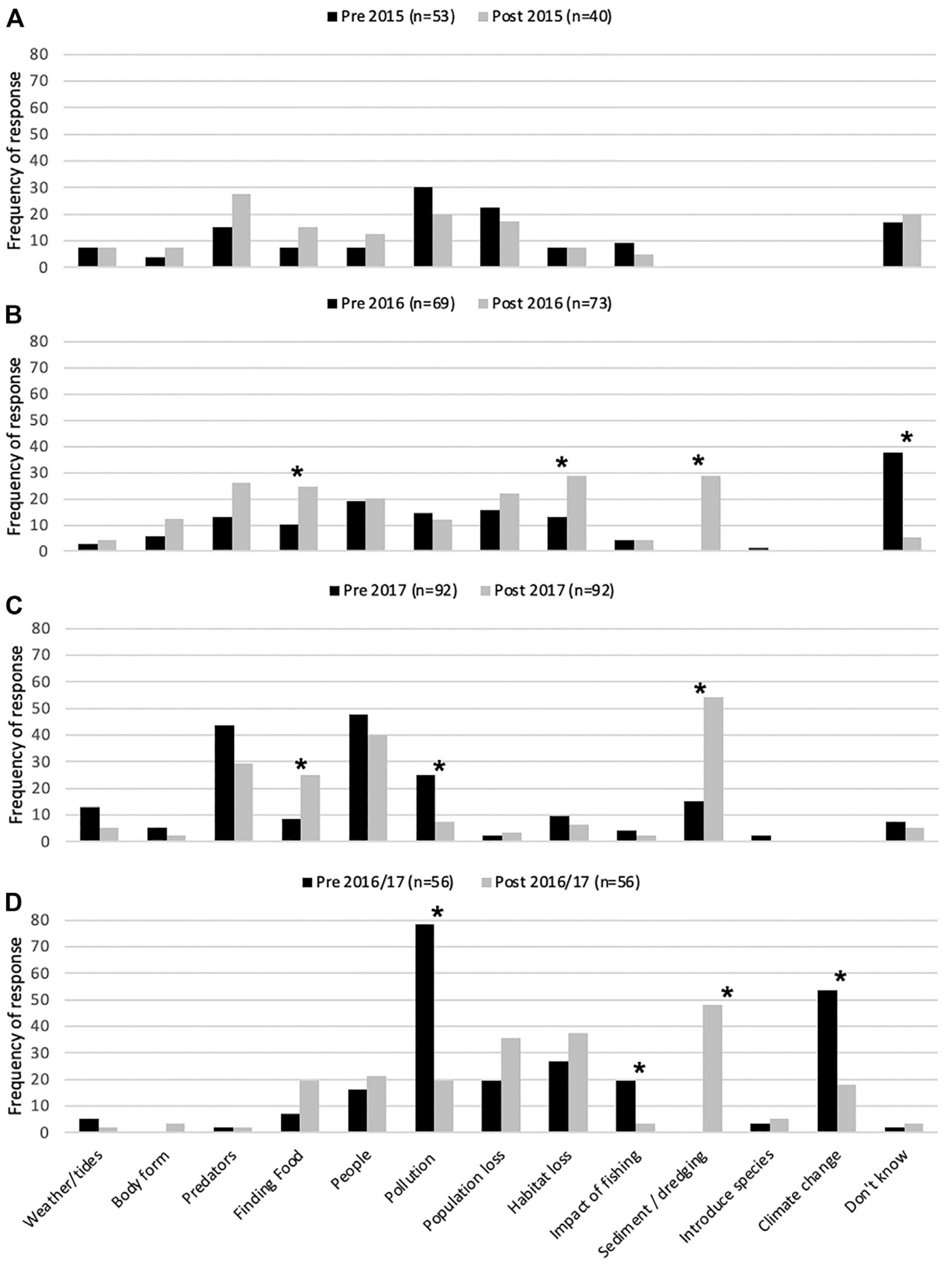

FIGURE 7 | Categories of response reflecting primary **(A–C)** and secondary **(D)** students' understanding of challenges faced by intertidal animals. *Significant differences pre - post for primary students 2016: sediment (0–29%, χ^2 (1, n = 142) = 21.07, p < 0.001, phi = −0.405, chi-squared test for independence with Yates' Continuity Correction), finding food (10–25%, χ^2 (1, n = 142) = 4.198, p = 0.040, phi = −0.190), habitat loss (13–29%, χ^2 (1, n = 142) = 4.326, p = 0.037, phi = −1.193), no response (38–6%, (χ^2 (1, n = 142) = 20.08, p = 0.000, phi = 0.349); primary students 2017: sediment (15–54%, p < 0.001, McNemar's test), finding food (8.7–25%, p = 0.009), pollution (25–8%, p = 0.003), predators (44–29%, p = 0.055); secondary students 2016/17: pollution (79–20%, p < 0.001, McNemar's test), climate change (55–18%, p < 0.001), impact of fishing (20–4%, p = 0.012), sediment (0–48%, p < 0.001).

diversity of challenges were suggested ranging from natural to anthropomorphic (**Figure 7**). The number of suggestions offered by individuals, as well as the diversity of categories of response were greater for primary students after longer interventions (e.g., 9 categories in 2015 vs 11 in 2017) (**Figures 7A–C**). Responses for pre 1-day intervention focused mostly on *pollution*, *population loss* and *predators*, while post-intervention awareness remained on the *impact of predators,* but extended to *difficulty of finding food* and the *impact of people*. In the longer intervention (2016), the most marked increase pre - post was the

TABLE 4 | Impacts of sediment on harbor plants and animals as described by secondary students in 2016/17 (n = 56 each, pre and post, analyzed using McNemar's test).

Impact themes	% Pre (n = 56)	% Post (n = 56)	p Value
Provides shelter/habitat	7.1	3.6	0.688
Provides nutrition	1.8	0	1.00
Disturbance to animal/habitat	19.6	42.9	0.002
Loss of food	7.1	41.1	<0.001
Decline in population/health	12.5	35.7	0.011
Reduced light	5.4	42.9	<0.001
Burial	1.8	28.6	<0.001
Reduced water quality	3.6	3.6	1.000
No response	58.9	5.4	<0.001

identification of *sediment* as a challenge, followed by *finding food* and *habitat loss* (all which were significant increases). This is of note as the latter two challenges are associated with a high sediment environment (e.g., predators cannot hunt effectively, seaweed photosynthesis is inhibited, filter feeders are impaired sorting plankton from sediment). Other categories exhibiting notable rise (>20% post intervention) included impacts of *predators, people* and *population loss*. It is also of note that the number of students able to answer this question post intervention also increased significantly (**Figure 7B**).

In 2017, responses were predominately in just three categories: impacts of *predators, people* and *sediment* (**Figure 7C**), with the most highly significant change pre - post being an increase in the frequency of *sediment* as a response. A probable effect of previous experience can be seen in some students (15%) identifying sediment as a challenge pre-intervention, whereas no student did in 2016. The only other response to increase significantly pre - post was *finding food*, suggesting new awareness that sediment affects the feeding behavior of many species. The significant decrease in *pollution* pre – post, is likely due to students being able to more clearly articulate specific challenges rather than catch-all terms like pollution, although during field work there was also very little evidence of visible pollution (e.g., rubbish).

At secondary level, students demonstrated some pre-existing knowledge of challenges facing organisms in the intertidal zone, with individuals expressing as many as five responses (pre -post $\bar{x} = 2.32 \pm 0.97$, $\bar{x} = 2.16 \pm 1.16$). In contrast to primary student responses, the key issues they identified pre-intervention were pollution (79%) and climate change (54.6%) (**Figure 7D**). These frequencies declined significantly post intervention, where, similar to primary students, the main issue became *sediment* (48%, a significant increase) as well as *habitat loss* (38%) and *population loss* (36%). *Impacts of fishing* decreased significantly pre – post (**Figure 7D**), possibly reflecting students' ability to give more specific challenges rather than popular catch-all ideas like pollution and over-fishing.

To interrogate students' knowledge gain about specific challenges faced by intertidal species secondary students were also asked to describe the impacts of sediment on harbor animals and plants (**Table 4**). The majority of students weren't able to give a response pre-intervention (59%) but this decreased significantly post-intervention (to 5%; $p < 0.001$). Five categories of responses all increased significantly pre - post including; *disturbance to animal/habitat*, *decline in population, loss of food, reduced light* and *burial* (**Table 4**), representing a diverse and accurate array of sediment impacts.

The positive effects on student's ability to identify intertidal species and understanding of the environment in which they live, indicate that Mm^2 provided an effective means to assess and monitor biodiversity in the intertidal zone, and joins other CS projects demonstrating the ability to collect valuable data for biodiversity monitoring (Cooper et al., 2007; Cox et al., 2012; Ballard et al., 2017b). The increase in specific understanding about anthropogenic factors affecting marine organisms is also condusive to a wide awareness of human impact and the need for stewardship.

Attitudes and Behaviours Towards the Marine Environment

As awareness is a precursor and motivator of attitudes and behaviors, student awareness about wider values of the ocean was assessed. Primary students were asked why it is important to look after the ocean's animals and plants. Their free-text responses revealed several themes including: *prevention of population decline*, *survival of the planet, our own survival, aesthetics, animal rights, animals needing care* and *for future generations* (**Figure 8**). In the 1-day intervention a strong animal-centric focus was clear, with students highlighting *animals rights* (pre and post), as well as concern about possible *population decline* (**Figure 8A**). There was also an increase pre - post in recognizing that *animals need care*, which likely stems from instructions given to students before surveying to handle the animals with care and return rocks to how they were found. *Aesthetics* was the only category of response that changed significantly, decreasing from pre to post (**Figure 8A**). In the 6-month intervention (2016), students also identified *population decline* as the top response pre-intervention (**Figure 8B**). However, post-intervention, there were significant increases in responses expressing an importance of ocean life to the *survival of the planet* and to *our own survival* (**Figure 8B**). In 2017, the students were even more aware of the importance of the ocean, with categories of response particularly widely distributed. A large proportion linked ocean organisms with our survival (providing us with food and oxygen); *our own survival* and *survival of the planet* were the most frequent responses (pre and post, **Figure 8C**). The frequency of these responses was also higher in 2017 than 2016, which may be attributable to the prior experience of students with Mm^2. *Aesthetics* was also a common post response, although counter to the pattern observed for 2015, it increased significantly pre – post (**Figure 8C**). It is possible that after extended engagement with life in the intertidal zone, students may have been more interested in looking after it as part of their intrinsic valuing of biodiversity (Chan et al., 2016).

Increased awareness of the marine environment and the environmental issues that affect it, ideally lead to change in our behaviors to reduce our environmental impact. Assessing such intentional behavior change is difficult but several short questions were asked to investigate student's awareness of their

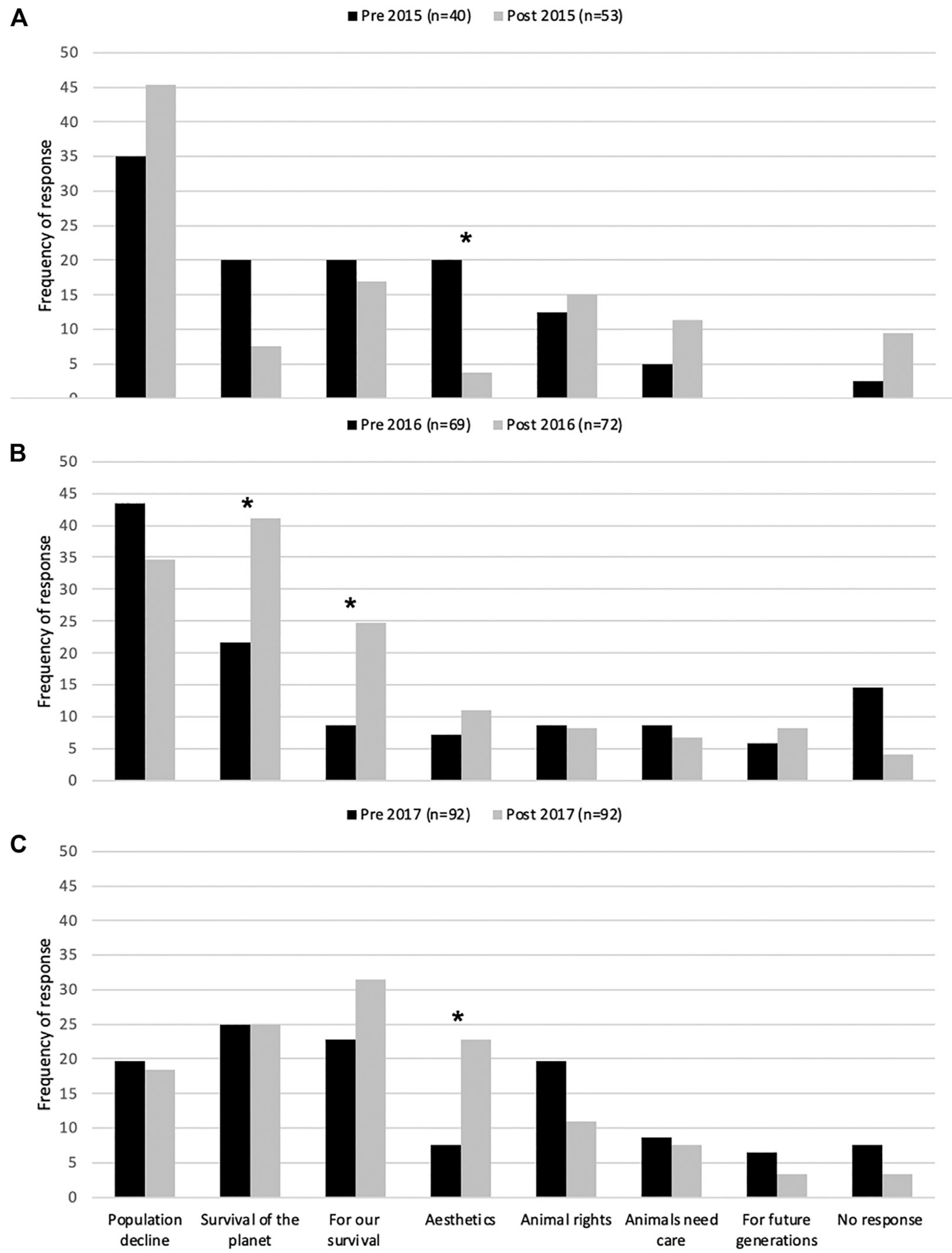

FIGURE 8 | Categories of response from primary students asked why they should look after the ocean's animals and plants across 3 years: **(A)** 2015, **(B)** 2016, **(C)** 2017. *Significant differences pre - post in 2015: aesthetics (χ^2 (1, n = 93) = 4.678, p = 0.031, phi = 0.259, chi squared test for independence with Yates' Continuity Correction); 2016: survival of the planet (χ^2 (1, n = 142) = 5.278, p = 0.022, phi = −0.208), our own survival (χ^2 (2, n = 142) = 5.348, p = 0.021, phi = −0.213; 2017: aesthetics (8 vs 23%; p = 0.003, McNemar's test).

scope for behavior change (**Figure 9**). Primary students were asked to describe in free text what they and their community could do to look after the seashore. After the 1-day intervention, three main themes emerged: *rubbish clean-up, care for wildlife* and *habitat protection* (**Figure 9A**). Cleaning up the rubbish was the most common response both pre (49%) and post (55%), which is perhaps not surprising as it is an achievable and popular activity with results that are immediately visible. Post intervention, significantly more students also identified *care for wildlife* as important (**Figure 9A**) and again, this is likely linked to students being told about the importance of ensuring that organisms were not disturbed through intertidal surveying.

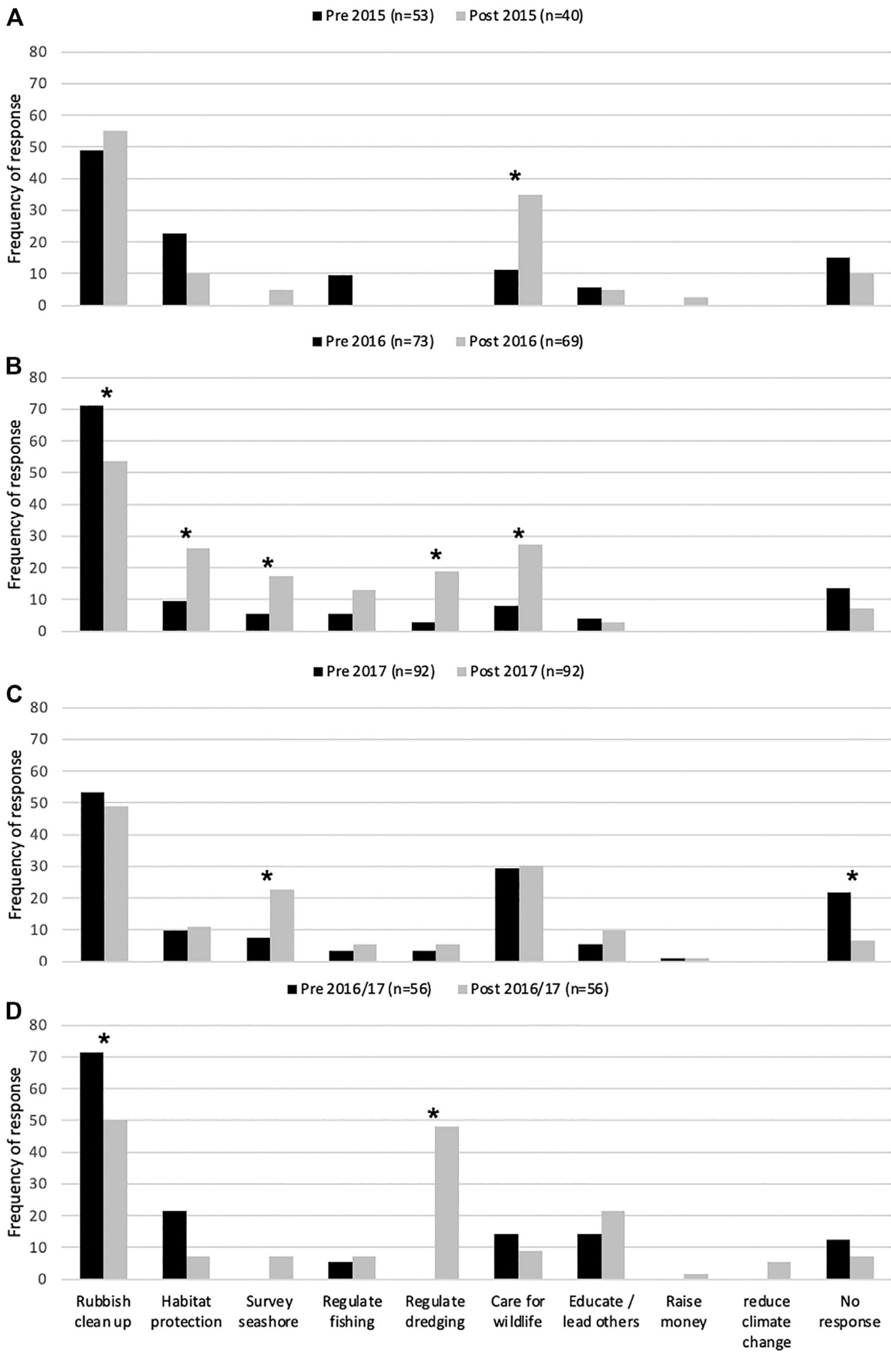

FIGURE 9 | Categories of response reflecting primary **(A–C)** and secondary **(D)** students' understanding of actions that they and their community could do to look after the seashore. *Significant differences pre - post for primary students 2015: care for wildlife (11 vs. 35%, χ^2 (1, n = 93) = 6.23, p = 0.013, phi = 0.285, chi squared test for independence with Yates' Continuity Correction); Primary students 2016: rubbish clean-up (91 vs 54%; χ^2 (1, n = 142) = 3.980, p = 0.046, phi = −0.182), care for wildlife (χ^2 (1, n = 142) = 7.842, p = 0.005, phi = 0.253), protect/restore habitats (χ^2 (1, n = 142) = 4.463, p = 0.035, phi = 0.196), survey the seashore (χ^2 (1, n = 142) = 3.913, p = 0.048, phi = 0.188) and regulate dredging (χ^2 (1, n = 142) = 8.104, p = 0.004, phi = 0.262); Primary students 2017: survey the seashore (8 vs. 23%: p = 0.003, McNemar's test), no response (22 vs 7% (p = 0.004); Secondary students 2016/17: cleaning up rubbish (71 vs. 50%; p = 0.012), regulate dredging (27 vs. 48%; p = 0.012), protect habitats (21 vs. 7%, p = 0.057).

After a 6 month intervention (2016), students were able to suggest many more ideas for how to care for the seashore and most of these increased pre – post (**Figure 9B**). The proportion of students that identified *rubbish clean-up* was still dominant pre-intervention but decreased significantly post. This may be linked with the significant increase pre to post for other ideas like, *care for wildlife*, *protect/restore habitats, survey the seashore* and *regulate dredging* (**Figure 9B**). In 2017, similar ideas were suggested in terms of *rubbish clean-up* or *care for wildlife*, and there was a significant increase pre-post in those noting they could *survey the seashore* to monitor its health (**Figure 9C**). Although for secondary students *cleaning up rubbish* remained the most common answer pre – post, this decreased significantly post intervention, possibly as consequence of an increased frequency of *regulate dredging* (**Figure 9D**). Further positive effects of the CS intervention can be inferred in not only a significant increase in the proportion of students able to provide a response, but also the average number of responses given by each student increasing post-intervention (**Figure 9**). Furthermore, students that had prior experience were able to make significantly more suggestions post intervention (pre – post, $\bar{x}$ = 1.32 ± 1.06, $\bar{x}$ = 1.62 ± 0.83) than those without ($\bar{x}$ = 0.98 ± 0.62, $\bar{x}$ = 1.16 ± 0.66; $F(1,90)$ = 9.33, p = 0.03, partial eta squared = 0.094).

This project extended student learning beyond the classroom to enhance their awareness of intertidal organisms, their environment and a new understanding of what they could do to better look after the environment. Although, any impact of the intervention on realised behaviour change remains unknown, it can be expected to have contributed a sense of civic responsibility for the local environment (environmental citizenship). According to Ballard et al. (2017a) definition, it also is expected that this extended CS intervention contributed to students' environmental science agency for future environmental citizenship through repeated experiences in the same place, their involvement in vigorous data collection and analysis, their sharing of results with relevant audiences (i.e. here this includes the other schools involved, marine scientists, the Port Authority and interested community members) and their identification of ways that they, and their community, could look after the environment in future. There remains relatively unexplored links between civic action and an individual's environmental knowledge and skill level (i.e. monitoring, assessing). For example, those students in the study with previous experience appeared to maintain more confidence in science skills, and it would be useful to know if this also propels intention to act and participate in environmental decision making in future. Evaluation instruments need to extend beyond assessing standard knowledge gain impacts on individuals and measure the degree of civic empowerment confired by CS projects (Schaefer et al., 2021) as well as investigate specifically how CS can be designed to "enhance the transformative aspects of CS at the society level" (Turrini et al., 2018, page 184).

Impact of Project Duration on Student Learning

It appears that CS interventions of longer duration and with specific focus on a local environmental issue had positive outcomes on multiple aspects of student learning, from improved understanding of the coastal environment and human impacts to development of science skills. After a one-day program, primary students' understanding of science changed from doing experiments at school to include field work, and their understanding of the purpose of doing surveys expanded from species and habitats to population size and environmental change, however failed to connect this to intertidal health. Although the Mm^2 survey focused their observations on a small area to discover many plants and animals that they had never noticed before, students ability to identify intertidal organisms, or the challenges they face, did not improve. Many students understood that they should look after marine organisms to prevent population decline, but they were less able to make further connections about the value of marine life to the wider environment or personal health, and associated actions to care for the environment.

By comparison, students were more able to make these cognitive extensions after a 6 months intervention. Not only was there a heightened ability to identify marine organisms and their challenges, particularly those associated with increased levels of sediment, there were stronger attitudes expressed about the value of marine species for our own survival and that of the planet. This was associated with the ability to articulate multiple ways to care for the marine environment, beyond picking up rubbish. In the second 6-month intervention (2017), where 41% of students had prior involvement (and thus ~12 months experience), learning outcomes appeared further augmented. This was particularly true for knowledge of the marine environment, challenges affecting marine species, environmental issues and solutions. These findings are of particular importance as, although an increase in knowledge-based performance is often observed where the participants are volunteers pursuing a personal interest (Brossard et al., 2005), it is not always observed when participants, like school students, are participating because they are enrolled in the class (Vitone et al., 2016).

It is of note that although students were interested in the CS project, perceived doing a Mm^2 survey as doing science, and felt they had developed more skills through the experience, this did not necessarily affect an increase in their feeling that they would make a good scientist. Other studies have made similar observations (e.g., adults training as naturalists not identifying themselves as a scientist or showing heightened interest in scientific endeavors (Merenlender et al. (2016)). Understandably, participating in CS is not necessarily a pathway to further science engagement and there remain many other cultural issues defining what we think makes a scientist. None-the-less, the longer interventions had further knock-on effects. Many of the Year 11 students extended their study into science fair projects (with most winning prizes at a local science competition). This was likely linked to their interest in the subject, but also the heightened confidence in carrying out a scientific investigation and skills in survey methods, data collection and data analysis.

Adaptive Learning on Embedding CS Within Schools

Given that extended involvement appeared to have had a positive effect on multiple student learning outcomes, it is disappointing to note that long term interventions in school programs are relatively rare. Many informal science education providers offer one-off experiences for schools that are a half- or 1-day in length. Many schools also engage in a specific enquiry topic for just a single term (10–11 weeks). This study suggests that extending interventions over two terms or more could be expected to improve learning outcomes. This will be particularly important for embedding wider community-level engagements, such as what this project offered by involving students in a fuller scientific process of engaging with scientists, designing their research approach and reporting their results back to stakeholders. Not only does this format clearly meets the "Nature of Science" goals of many science curricula (Hipkins and Bull, 2015; Shah and Martinez, 2016; Nistor et al., 2019), such youth opportunities to develop expertise and confidence in data production and sharing can be expected to develop science citizenship skills. This is certainly all expressed in the goal of the NZ science curriculum in enabling students "*to use their science skills to participate as critical, informed and responsible citizens*" (Ministry of Education, 2007, page 17). It is recognized that to induce learning processes that develop scientific enquiry skills and empower students to reach civic responsibility, extended involvement in multiple stages of the science process is important (Danielsen et al., 2014; Shah and Martinez, 2016; Turrini et al., 2018; Bonney et al., 2009a). Taking it a step further, co-development of CS projects, where the citizens are involved in all aspects of the scientific process, can lead to better understanding of the scientific outcomes, as well as encouraging stewardship and fostering empowerment (Kieslinger et al., 2018).

Furthermore growing such opportunity for civic engagement via CS interventions should not be reserved for older students. Students from Year 3 to 11 took part in all aspects of the Sediment and Seashores Project. Although there were concerns that the early primary classes might be too young, their learning outcomes highlight that this was not the case. Indeed, the youngest class (Year 3) was the most enthusiastic in their learning and although they needed further parental support for tasks like data recording, this provided a unique opportunity to involved a diversity of adults, who otherwise might not have choosen to participate in CS. Thus the potential for CS interventions to extend community involvement in the school-based learning environment appears significant. Comments collected from teachers at the end of the project indicated multiple reasons for their decision to engage in the project, but many involved finding ways to further local community engagement. These ranged from the leadership and guidance provided by scientists, to the opportunity to study a local context and environment, where students' could apply their science skills. Teachers clearly valued the project providing an authentic learning environment with local context, as indicated by comments like "*getting classes involve in real science/fieldwork/analysis*" and "*it connected the students with their local environment, and made them become more aware of the importance of knowing if things change, to find out why and what they can do to protect their harbour.*"

This study provides one of the few assessments of science inquiry skills through CS in schools and provides insight on how CS experiences can enrich science learning outcomes for students. As an evaluation of an adaptive program evolving across years, it is not without methodological challenges that would be beneficial to address in future studies, particularly as enthusiasm grows for embedding CS in classrooms (Nistor et al., 2019). For instance, student learning gains associated with participation in a CS project are likely to be entangled with classroom-based learning (Vitone et al., 2016). There is also relevant debate about the use of pre test versus restrospective pre test to assess attitudes (Vitone et al., 2016). A response shift has consistantly been found to be higher with retrospective pre test (Sibthorp et al., 2007). This response shift bias is expected in situations when the participant have limited knowledge before engaging with the intervention, suggesting that the timing of the pre test needs to be strategically considering in planning the assessment (Vitone et al., 2016).

CONCLUSION

As demonstrated here, school science education can clearly be enriched in multiple ways through participation in a CS project. These included increasing content-specific knowledge, science skills, and awareness of environmental issues and our role as stewards. In this study, students and their teachers gained direct experience of the marine intertidal environment and in environmental monitoring methods. Students learned about the value of a healthy ecosystem and gained a greater understanding of how they can participate in civic conservation action. The project created relationships between schools, community and scientists and provided opportunity for schools to become involved in an authentic research project and support the growth of critical, informed and responsible citizens.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

The main research was undertaken by SC with consultation by JR regarding survey methods and JS regarding statistical topics. The article was written by SC with editing help of JR.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.674883/full#supplementary-material

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Expanding the Boundaries of Informal Education Programs: An Investigation of the Role of Pre and Post-education Program Experiences and Dispositions on Youth STEM Learning

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For generations educators have been supporting children and youth's science, technology, engineering, and mathematics (STEM) learning through informal education programming. Such programming includes a wide variety of outdoor education programs, camp programs, and increasingly targeted STEM programs run afterschool, on weekends, and over the summer months. However, despite the positive impacts these programs have, few would argue that these programs could not be improved or be designed to better meet the needs of a broader and more diverse population of learners. Arguably, one major flaw in how most educators have approached the design and improvement of these programs—a flaw that permeates almost all informal STEM education efforts–is that either explicitly or implicitly, the focus of educators has been exclusively on what happens during the program itself. Superficially this seems reasonable. After all, the time children/youth are within the temporal and physical boundaries of the program, class, or museum is the time when educators have maximal control over events. However, given what is known about how people learn (National Academies of Sciences, 2018), we argue that this long-standing approach needs to be reconsidered.

Keywords: informal education, free-choice learning, pre-experiences, post-experiences, summer programs

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INTRODUCTION

STEM Learning

Three key ideas underlie our current understanding of how people in general and children in particular learn STEM. The first key idea is that STEM learning is continuous, cumulative, and constructed. The second key idea is that STEM learning is highly personal and driven by individual needs and interests. The third key idea is that STEM learning is always situated within a complex learning ecosystem.

Children learn STEM across time and space, in and out of school, and by using a variety of community resources and networks (National Research Council (NRC), 2009; Stocklmayer et al., 2010; The Organization for Economic Co-operation and Development (OECD), 2012). The result is that STEM learning is rarely an instantaneous event, but rather an unfolding, cumulative process (National Academies of Sciences, 2018). Typically, individuals acquire STEM understanding through a continuous accumulation of experiences from many different sources and times (Lave and Wenger, 1991; Caillot and Nguyen-Xuan, 1995; Korpan et al, 1997; Anderson et al, 2000; Miller, 2010;

Brotman et al, 2011). Thus, over a lifetime, individuals construct their knowledge about the world, as well how best to use that knowledge, not from one, but from literally hundreds if not thousands of STEM experiences and exposures. This "truism" relates to applications of knowledge and skills, and to perceptions of identity and self-efficacy. So, for example, one's self perceptions of how to solve a STEM-related problem are equally a product of one's prior knowledge and experience and one's self-efficacy around creativity and STEM (National Academies of Sciences, 2018).

For most of the 20th century the prevailing view was that learning was a generalizable, linear, and predictable accumulation of knowledge. Everyone learned in the same way, and as long as the same information was consistently and appropriately presented, every individual would learn, and each would learn the same things. These ideas have often been described as the "transmission-absorption" model of learning (cf., Roschelle, 1995). However, despite the fact that the general process of learning is comparable in most humans, how these processes affect the products of learning are anything but comparable. Learning is a uniquely individual, idiosyncratic event; no two people learn exactly the same thing in quite the same way (Fosnot and Perry, 2005; National Academies of Sciences, 2018). Equally as important, is motivation for and receptivity to learning. Each learner's unique interests, needs, prior experience, and motivations primarily drive these factors (Immordino-Yang, 2015; Falk and Dierking, 2018). Interest and its correlate, motivation, have been shown to be crucial drivers of learning, and therefore have become a topic of increasing importance to STEM learning researchers and practitioners (cf., Falk, et al., 2016a; Renninger and Hidi, 2016).

As described in a recent National Research Council's report on out-of-school learning (National Research Council (NRC), 2015), today's children learn across their entire lives, in and out of school. The acquisition of important STEM capabilities such as creativity, interest and understanding, as well as more generic abilities such as problem solving are supported by a wide range of in-school and out-of-school educational resources (National Research Council (NRC), 2009; Falk and Dierking, 2010; Nature, 2010; Stocklmayer et al, 2010; National Research Council (NRC), 2015). Collectively, these educational resources can be thought of as comprising a single, large, and complex ecosystem of learning (Traphagen and Traill, 2014; Falk, et al., 2015). The ecosystem concept is well suited to describing interactions between people and their environment including processes for learning and developing new knowledge in a variety of contexts (Jackson, 2013; Falk et al., 2020), as it has become increasingly clear that learning rarely occurs in discrete, bounded moments in time, but more typically, is the consequence of sets of cumulative experiences, across multiple learning platforms, e.g., organized classes, broadcast and print media, digital resources, and informal experiences at places like museums (Falk and Needham, 2013; Barron et al., 2014; Azevedo, 2015).

Despite the growing consensus around these three key understandings (cf., National Academies of Sciences, 2018), virtually all informal STEM education programs largely operate as if historic understandings of learning still pertain. Furthermore, even though children's learning is continuous and incremental and situated within a larger ecosystem of learning, most informal programs are still designed, either explicitly or implicitly, as if learning begins when the child/youth enters the educational program and ends when they exit the program. Regardless of the knowledge that STEM learning is always driven by an individual's prior experiences, interests, motivations and dispositions, informal educators continue to assume that participants of the same age all have the same educational starting point. Although educators have consistently sought to improve the design of their STEM education programs, either through better quality lessons, improved facilitation, or creation of more exciting, hands-on approaches, as suggested above, few have fully accommodated these three learning realities. As a consequence, improvement efforts in current informal STEM education programs have led to, at best, only incremental improvements in learner outcomes.

Important Pre-Experience Factors

When educators have considered pre-experience factors that might influence learner outcomes, they have typically focused on demographics. For example, it is long been argued and extensively documented that factors such as race-ethnicity, gender, and socioeconomic status are critical determinants of educational success (e.g., López, 2002; Riegle-Crumb, 2006; Carter, 2012; Becares and Priest, 2015; McGee, 2018). However, there are other, potentially equally important influencing factors. Research suggests that five other factors, all of which are non-demographic, might also influence informal education outcomes. In particular, these are: 1) The number and frequency of out-of-school experiences (e.g., Falk and Needham, 2013; Falk and Dierking, 2018; National Research Council (NRC), 2015; Tai and Maltese, 2010); 2) Parental attitudes and support (e.g., Archer, et al., 2010; Barron et al., 2009; Falk, et al., 2016b); 3) Personality constructs like sociability (often referred to as introversion vs. extroversion) (e.g., Topping, 2005; Noftle and Robins, 2007; Poropat, 2009); 4) Prior experiences (e.g., Archer, et al., 2010; Frenzel et al., 2010); and 5) children/youths' self-related motivations for participating in an informal experience (Falk, 2009; 2018). In theory, any one of these factors, for example the motivations of why a child might choose to attend an informal experience, could significantly change the trajectory of a child's long-term learning pathway, but detailed research is lacking.

In other words, the ability of any particular informal STEM education program to influence the short and long-term learning trajectories of children is in theory only partially determined by the quality of what happens during a particular informal program. The fact is, these programs likely make a disproportionate impact on children relative to the time invested, but other factors, over and beyond these programs also matter, including affecting how particular children are likely to benefit from such programs. As argued by Falk and colleagues (Falk and Dierking, 2018; Falk, Koke, Price and Pattison, 2018), no single experience or factor is likely to be the sole causative influence on learning outcomes. For most children/youth, most of the time, all experiences and life factors work synergistically, though one or another may be disproportionately important. The question remains, though, is it possible to determine for any particular educational experience, which of these many factors/variables might be disproportionately important? The exploratory research described here was an effort to investigate the relative impact of a range of pre-entry conditions on the short and long-term outcomes of children participating in a one-week summer STEM camp experience with the hope of better understanding which, if any of these factors most contributed to children/youth's STEM learning, and if so how this information might be used to advance the quality of informal STEM education.

TABLE 1 | Current and previous participant recruitment and survey completion statistics.

Time-point	Solicited	Participated	Participation rate (%)
T1	2,883	560	19.4
T2	2,900[a]	991	34.1
T3	1,364	196	14.4
T1+T2+T3	2,883	100	3.5
2016 cohort	7,234	130	1.8
2015 cohort	7,703	99	1.3
2014 cohort	6,904	80	1.2
2013 cohort	6,159	43	0.7

[a]*This is an approximation of the actual number of 10–12 year old youth attending the 100 camps on the last day; exact figure is not known by the research team.*

MATERIALS AND METHODS

This study was designed to explore the impacts pre-program experiences and dispositions had on the learning outcomes of youth participants in a one-week STEM and invention-focused, summer camp program. The program in question was called Camp Invention®. We used the outcome variables emphasized by this particular informal education program, specifically creativity, STEM interest and problem solving. We selected as independent variables five possible factors we felt were potentially important and readily measurable: parental support, introversion/extroversion, motivations for attending, the number of prior STEM-related experiences and prior experiences with this particular summer camp program.

Design In order to investigate our research questions, we collected data from "Current Participants" and "Previous Participants." The Current Participant group was derived from children attending Camp Invention® during the summer of 2017. The initial intent was to include only campers that were 11–12 years old. However due to low participation rates early in the data collection process, the decision was made to also recruit 10–11 year old youth. We collected data from current participants at three points in time: 1) Time-point one (T1), was an online survey taken two to four weeks prior to the start of camp; 2) Time-point two (T2), was a paper survey administered during the last day of camp; and 3) Time-point three (T3) was an online survey intended to be completed by participants two to three months after the conclusion of Camp.

The Previous Participant group was derived from campers who had attended Camp Invention® when they were 11–12 years old prior to 2017. Data was collected for four previous Camp Invention® participant cohorts, those attending Camp in 2016, 2015, 2014, and 2013. We measured the study variables across all groups and timepoints.

Participants

The Current Participant study group was intended to be a longitudinal, within-subjects design study, with the sample composed of individuals tracked over all three time-points. Recruitment for the Current Participant group was performed via email. A survey of 2017 Camp Invention® program and participant rosters was utilized to target camp locations with the most registered 10–12 year old youth. Parents were emailed a recruitment request outlining the goals of the research, a link to the T1 online survey, and were asked for their written consent to collect data from their child across all three time-points of the study. Parents were instructed to encourage their children to complete the survey on their own, however, they could assist their children if the children requested or required it. There was no time limit for survey completion, however, it would have had to be completed in "one sitting" as a second accessing of the survey link would have potentially initiated a second survey for the same child. Solicitation and data collection for the T1 survey continued until the minimum target sample size of 500 was achieved. A total of 560 10–12 year old youth collectively registered to attend 153 different camps, completed the T1 survey.

The T2 survey was in paper format and was administered by camp staff on the last day of camp. Camp staff were instructed to encourage the children to complete the survey on their own, however, they could assist the children if the children requested or required it. Staff were instructed to allot 15 min for students to complete the survey; though there was no actual enforcement of a time limit on completion. Ten to 12 year old campers who had not taken the T1 survey were invited to complete the T2 survey provided that they had returned a completed parental consent form that was made available on the first day of camp. In total, 991 T2 surveys were completed from 100 camp locations.

The T3 survey was an online survey. The web-link for the T3 survey was emailed to the parents of all campers who completed either the T1, the T2, or both surveys. Again, parents were instructed to encourage their children to complete the survey on their own, however, they could assist their children if the children requested or required it and no time limit was imposed. Of the 196 participants that completed the T3 survey, only 100 had also completed the T1 and the T2. Given the exploratory nature of this study and the greater importance of the delayed post-test, we felt it justified to just focus on the comparison between T1 and T3. Accordingly, we opted to compare the responses of the 560 participants who had completed a T1 survey–pre-camp sample–with the responses of the 196 participants completing a T3 survey–short-term post-camp sample - from a between-subjects design perspective.

To recruit participants in the Previous Participant study, Camp Invention® participant rosters from 2016, 2015, 2014, and 2013 were utilized to obtain parent email addresses for campers who were 11–12 years old at the time of their Camp participation for each of the four target years. Parents were emailed a recruitment request outlining the goals of the research, a link to the online survey for their child's cohort, and were asked for their consent and their child's participation. Parents were instructed to encourage their children to complete the survey on their own, however, they could assist their children if the children requested or required it and no time limit was imposed. Again to maximize statistical power, data was collapsed into a single Past Participant group for the purposes of statistical analyses. A total time-point TX sample was 352 youth. **Table 1** summarizes data collection statistics for both the Current Participants and Previous Participants study samples. No significant sex differences were found for any of the time-points.

Intervention

Camp Invention® is a summer day-camp program in which children between the ages of 5 and 12 years engage in hands-on activities that promote STEM interest and participation and the building of 21st century learning skills such as creativity and problem solving (cf., Trilling and Fadel, 2009), through the lenses of invention and entrepreneurship. Developed by educators, the curriculum aligns with state and national standards. Hundreds of schools and districts across the country host Camp Invention® programs, with millions of children having participated over the 27 years of its existence. Evaluation studies (e.g., ChangeMaker Consulting, 2014; Kent State University, 2004:; Scarisbrick-Hauser and Hauser, 2009) have reported that children who participate in Camp Invention® showed significant short-term improvements in the program's defined goals of increasing children's creativity, STEM interest, and problem-solving skills.

Dependent Variables

Given that creativity, STEM interest, and problem-solving skills were both widely shared programmatic goals for other informal education experiences, and there was strong, pre-existing evidence that the Camp Invention® experience resulted in a majority, but likely not all of children in the program achieving some measure of these outcomes, we opted to use these three areas of learning as dependent variables. All variables were measured across multiple time points as designated.

To investigate creativity, we utilized existing, age-appropriate measures for Mechanical Science Creativity and Creative Self-Efficacy. For STEM interest, we utilized existing, age-appropriate measures for Science Relevance, Self-Concept in Science, and Science Interest. Finally, we utilized an existing, age-appropriate measure of Critical Thinking to investigate problem-solving skills.

Mechanical Science Creativity was measured using five items from the Mechanical/Scientific domain of Kaufman's Domains of Creativity Scale (Kaufman, 2012). All items were captured using a six-point Likert scale ranging from one, "Much less creative" to six, "Much more creative." Participants were provided the prompt of, "Compared to kids your age, how creative would you rate yourself for the following?" Example items include, "Carving something out of wood or similar material" and "Helping to carry out or design a science experiment."

Creative Self-Efficacy was measured using seven items from the Short Scale of the Creative Self (Karwowskiet al., 2018). All items were captured using a six-point Likert scale ranging from one, "Strongly Disagree" to six, "Strongly Agree." Participants were provided the prompt of, "Tell us how much you disagree or agree with each of the statements below." Example items include, "I think I am a creative person" and "Being a creative person is important to me."

Science Relevance, Self-Concept in Science, and Science Interest were all measured using items drawn from the ASPIRE survey (DeWitt et al., 2011) and ROSE Questionnaire (Schreiner and Sjøberg, 2004). Science Relevance and Self-Concept in Science items were captured using six-point Likert scales ranging from one, "Strongly Disagree" to six, "Strongly Agree." Participants were provided the prompt of, "Tell us how much you disagree or agree with each of the statements below." Example items include, "Science and engineering tell us about how people think and behave" for Science Relevance and "I find Science and engineering harder than most subjects" (reverse coded) for Self-Concept in Science. Science Interest items were captured using a six-point Likert scale ranging from one, "Dislike a lot" to six, "Like a lot." Participants were provided the prompt of, "How much do you like finding out about the following things either in or out of school?" Example items include, "Mixing materials together to see what happens" and "What it's like on other planets and exploring space."

Critical Thinking was measured using six items developed by the research team. All items were captured using a five-point Likert scale ranging from one, "Never" to five, "Always." Participants were provided the prompt of, "How often do the following things happen?" Example items include, "When facing a problem, I always think of lots of options" and "I keep my mind open to different ideas when planning to make a decision." Principle Components Analysis results for these five items revealed factor loadings ranging from 0.497 to 0.751 and the single factor solution for the five items explained over 41% of the variance in item responses.

Independent Variables

Next, based upon the literature cited above, we created a group of five "Potential Influence" variables that we hypothesized might have varying influence on these outcome variables:

- Out-of-School STEM Experiences (other than Camp Invention®)
- Parental Attitudes toward science and engineering
- Sociability (a personality measure of introversion vs. extroversion)
- Reason for Attending Camp (was the motivation related to content/learning or some other reason such as being with friends or parent made them go)
- Prior Camp (Invention) (s) Attended (was a proxy for prior experience and social capital).

As above, all items were based upon pre-existing, validated, age-appropriate measures.

Out-of-School Experiences were measured using five items derived from the Multiple Institute Science Center Effects Study (Falk et al., 2017). All items were captured using a six-point Likert scale ranging from one, "Never" to six, "Almost daily."

Participants were provided the prompt of, "Not including homework of stuff for school, how often do you do the following things outside of school." Example items include, "Use the internet to search for or learn about science or engineering related topics" and "Read books or magazine articles about science or engineering."

Youth perceptions of their Parent's Attitudes were measured using four items from the ASPIRE survey (DeWitt et al., 2011). All items were captured using a six-point Likert scale ranging from one, "Strongly Disagree" to six, "Strongly Agree." Participants were provided the prompt of, "Tell us how much you disagree or agree with each of the statements below." Example items include, "My parents want me to become a scientist or engineer when I grow up" and "My parents expect me to do well in school, especially in science." T1 scores for all youth were divided at the median. Due to the positively skewed results–in general youth scored toward higher numbers on the Likert scale–a median split was used for dividing youth into low and high categories. Individuals with T1 scores less than the median were considered "Low" on these two dimensions while individuals with T1 scores on these two dimensions scoring greater than the median were considered "High."

Sociability was comprised of three separate items and measured on a five-point Likert scale ranging from one, "Almost never" to five, "Almost always." The three items were "I like to meet with other people," "I like to be with others," and "I like to talk with others." Collectively, these items came from existing personality measures of introversion/extroversion (Noftle and Robins, 2007; Thompson, 2008). As with perceptions of Parent's Attitudes, responses were skewed toward higher numbers on the Likert scale. Using a median split, greater sociability (i.e., extroversion for the purposes of this analysis) was designated as "High" while low sociability (i.e., introversion for the purposes of this analysis) was designated as "Low."

Reason for Attending Camp was a dichotomous variable derived from five potential reasons the participant was or had attended camp. The five potential reasons were, "I want to be with my friends," "I don't want to go but my parent/guardian is making me go," "I want to learn about invention," "I want to learn about science and engineering," and "I just want to do something fun during the summer." Participants were asked to rank the statements in the order that they were most appropriate to them. Ranking a statement with the number 5 indicated that it was the most appropriate, or matching, statement for that participant's reason for attending camp. Ranking a statement with the number 4 indicated that it was the second most appropriate, etc. Participants who indicated "I want to learn about invention" or "I want to learn about science and engineering" as their most appropriate reason for attending were pooled into one "learning" category, and for the purposes of this analysis, were considered "High." Participants who chose any of the other three statements as their most appropriate reason for attending were pooled into a "not-for-learning" category, and for the purposes of this analysis, were considered "Low."

Prior Camps Attended was measured by the number of times a participant had previously attended a Camp Invention® program. Individuals who had never attended Camp Invention® before or only attended once were designated as "Low." Individuals who had attended two or more Camp Invention® camps before were designated as "High."

Within the scope of the aforementioned variables, one goal of this study was to find out which children benefitted the most from Camp Invention® and which children benefitted the least and why. Additionally, we wanted to investigate if the influences of the predictor variables on the outcome variables persisted over time, and if so, for which children, why and over what duration.

RESULTS

An Independent Samples *t*-Test was conducted to investigate differences in outcome mean scores between time-points T1 and T3 for the Current Participant group. In keeping with the exploratory nature of this research, "significance" was defined as having a probability of 0.1 or less (that the likelihood of a result occurring randomly or by chance was less than one in a ten). NOTE: In tables, a probabilities of <0.05 are indicated in bold; probabilities of <0.1 are indicated in underlined; and probabilities of >0.1 are indicated in italic.

Table 2 summarizes the differences between the T1 aggregate and T3 aggregate outcome variable mean scores. The short-term changes in mean scores in youth attending Camp Invention® between the 560 T1 (just prior to attending Camp) and 196 T3 (a couple of months subsequent to attending Camp) participants were statistically significant and positive for the measures of Creative-Self Efficacy (t (754) = −2.731, p = 0.007) and Science Interest (t (754) = −3.271, p = 0.001).

An additional Independent Samples *t*-Test was conducted to investigate differences in outcome mean scores between the T1 aggregate group and the combined Past Participant group samples. **Table 3** summarizes the differences between the 560 T1 aggregate and 352 Past Participant's outcome variable mean scores. There were positive and statistically significant differences in four out of the five scores–Creative-Self Efficacy, Science Relevance, Self-Concept in Science, Science Interest, and Critical Thinking. The lone exception was Mechanical Science Creativity which showed no significant change between the two groups.

Pre-Camp

A series of Simple Regression models were conducted for the Current Participant sample to investigate the difference in predicted Outcome variable scores at time T3 based on High or Low T1 Potential Influence scores. **Table 4** summarizes the results of these Simple Regression analyses for Current Participants on each of the six dependent variables–Mechanical Science Creativity, Creative Self-Efficacy, Science Relevance, Self-Concept in Science, Science Interest, and Critical Thinking. All statistically significant differences (bold or italic) in **Table 4** represent a positive difference between the High and Low Potential Indicator variables. In other words, the mean scores of the High group are significantly greater than the mean scores of the Low group.

TABLE 2 | Aggregate T1 to T3 outcome variable means independent samples *t*-Test.

Outcome variable	T1 mean	T1 Std. Dev	T3 mean	T3 Std. Dev	t Statistic	Significance
Mechanical science creativity	4.45	0.90	4.46	0.83	−0.057	*0.954*
Creative self-efficacy	4.91	0.99	5.11	0.80	−2.731	**0.007**
Science relevance	4.82	0.90	4.90	0.88	−1.134	*0.257*
Self-concept in science	4.33	0.99	4.46	0.96	−1.539	*0.124*
Science interest	3.80	0.80	4.02	0.79	−3.271	**0.001**
Critical thinking	3.87	0.66	3.93	0.60	−1.137	*0.256*

TABLE 3 | Aggregate T1 to past participant outcome variable means independent samples *t*-Test.

Outcome variable	T1 mean	T1 Std. Dev	PP mean	PP Std. Dev	t Statistic	Significance
Mechanical science creativity	4.45	0.91	4.44	0.88	0.289	*0.773*
Creative self-efficacy	4.91	0.99	5.03	0.80	−2.027	*0.043*
Science relevance	4.82	0.90	5.03	0.83	−3.577	*0.001*
Self-concept in science	4.33	0.99	4.48	0.98	−2.172	*0.030*
Science interest	3.80	0.80	4.05	0.73	−4.774	*0.001*
Critical thinking	3.87	0.66	3.96	0.58	−2.227	*0.026*

TABLE 4 | Current participant differences in T3 Outcome variable scores as a function of high/low T1 Potential Indicator variables.

Outcome variable	Predictor variable	Hi - low difference	Test statistic	Significance
Mechanical science creativity	Out-of-school experiences	0.510	3.054	*0.003*
Mechanical science creativity	Parental attitudes	0.391	2.318	*0.023*
Mechanical science creativity	Sociability	−0.066	−0.381	**0.704**
Mechanical science creativity	Previous camps	0.281	1.648	**0.103**
Mechanical science creativity	Reason for attending	0.341	1.955	0.054
Creative self-efficacy	Out-of-school experiences	0.235	1.502	**0.137**
Creative self-efficacy	Parental attitudes	0.092	0.581	**0.563**
Creative self-efficacy	Sociability	0.071	0.451	**0.653**
Creative self-efficacy	Previous camps	0.596	3.410	*0.001*
Creative self-efficacy	Reason for attending	−0.066	−0.407	**0.685**
Science relevance	Out-of-school experiences	0.837	5.388	*0.001*
Science relevance	Parental attitudes	0.738	4.649	*0.001*
Science relevance	Sociability	0.260	1.496	**0.138**
Science relevance	Previous camps	0.001	0.006	**0.996**
Science relevance	Reason for attending	0.684	4.123	*0.001*
Self-concept in science	Out-of-school experiences	0.625	3.554	*0.001*
Self-concept in science	Parental attitudes	0.327	1.783	0.078
Self-concept in science	Sociability	0.038	0.203	**0.839**
Self-concept in science	Previous camps	0.034	0.185	**0.853**
Self-concept in science	Reason for attending	0.374	1.990	0.050
Science interest	Out-of-school experiences	0.398	2.446	*0.016*
Science interest	Parental attitudes	0.091	0.545	**0.587**
Science interest	Sociability	0.192	1.156	**0.251**
Science interest	Previous camps	0.202	1.217	**0.226**
Science interest	Reason for attending	0.129	0.747	**0.457**
Critical thinking	Out-of-school experiences	0.173	1.518	**0.116**
Critical thinking	Parental attitudes	−0.001	−0.007	**0.994**
Critical thinking	Sociability	0.050	0.446	**0.656**
Critical thinking	Previous camps	0.358	3.390	*0.001*
Critical thinking	Reason for attending	0.099	0.869	**0.387**

Out-of-School Experiences explained a significant proportion of the variance for each of these six statistically significant outcome variables. The following represent the variance explained and effect sizes for each of the six outcome variables: Mechanical Science Creativity (R^2 = .089, F (1,95) = 9.328, p = 0.003), (β = 0.510, t (95) = 3.054, p = 0.003). Science Relevance (R^2 = 0.232, F (1,96) = 29.033, p < 0.001), (β = 0.837, t (96) = 5.388, p < 0.001). Self-Concept in Science (R^2 = 0.118,

TABLE 5 | Past participant difference in predicted outcome variable scores based on high/low predictor variable group.

Outcome variable	Predictor variable	Hi - low difference	Test statistic	Significance
Mechanical science creativity	Out-of-school experiences	0.579	6.605	*0.001*
Mechanical science creativity	Parental attitudes	0.437	4.855	*0.001*
Mechanical science creativity	Sociability	0.183	1.976	*0.049*
Mechanical science creativity	Previous camps	0.139	1.487	**0.138**
Mechanical science creativity	Reason for attending	0.289	−3.093	*0.002*
Creative self-efficacy	Out-of-school experiences	0.500	6.101	*0.001*
Creative self-efficacy	Parental attitudes	0.352	4.177	*0.001*
Creative self-efficacy	Sociability	0.215	2.512	*0.012*
Creative self-efficacy	Previous camps	−0.138	−1.594	**0.112**
Creative self-efficacy	Reason for attending	0.174	−1.980	*0.048*
Science relevance	Out-of-school experiences	0.670	8.258	*0.001*
Science relevance	Parental attitudes	0.677	8.377	*0.001*
Science relevance	Sociability	0.271	3.097	*0.002*
Science relevance	Previous camps	0.030	0.336	**0.737**
Science relevance	Reason for attending	0.353	−3.992	*0.001*
Self-concept in science	Out-of-school experiences	0.651	6.558	*0.001*
Self-concept in science	Parental attitudes	0.577	5.734	*0.001*
Self-concept in science	Sociability	−0.040	−0.383	**0.702**
Self-concept in science	Previous camps	0.087	0.819	**0.413**
Self-concept in science	Reason for attending	0.287	−2.686	*0.008*
Science interest	Out-of-school experiences	0.326	4.265	*0.001*
Science interest	Parental attitudes	0.243	3.146	*0.002*
Science interest	Sociability	0.245	3.172	*0.002*
Science interest	Previous camps	0.012	0.151	**0.880**
Science interest	Reason for attending	0.120	−1.495	**0.136**
Critical thinking	Out-of-school experiences	0.186	3.019	*0.003*
Critical thinking	Parental attitudes	0.135	2.175	*0.030*
Critical thinking	Sociability	0.255	4.174	*0.001*
Critical thinking	Previous camps	0.016	0.251	**0.802**
Critical thinking	Reason for attending	0.053	−0.833	**0.405**

F (1,94) = 12.629, p = 0.001), (β = 0.625, t (94) = 3.554, p = 0.001). And Science Interest (R^2 = 0.059, F (1,96) = 5.985, p = 0.016), (β = 0.398, t (96) = 2.446, p = 0.016).

Parental Attitudes explained a significant proportion of the variance for three of the six outcome variables. The following represent the variance explained and effect sizes for each of these three statistically significant outcome variables: Mechanical Science Creativity (R^2 = 0.053, F (1,96) = 5.374, p = 0.023), (β = 0.391, t (96) = 2.318, p = 0.023). Science Relevance (R^2 = 0.182, F (1,97) = 21.615, p < 0.001), (β = 0.738, t (97) = 4.649, p < 0.001). And Self-Concept in Science (R^2 = 0.032, F (1,95) = 3.178, p = 0.078), (β = 0.327, t (95) = 1.783, p = 0.078).

Previous Camps explained a significant proportion of the variance for three of the six outcome variables. The following represent the variance explained and effect sizes for each of these three statistically significant outcome variables: Creative Self-Efficacy (R^2 = 0.018, F (1,95) = 1.745, p < 0.001), (β = 0.596, t (95) = 3.410, p < 0.001). And Critical Thinking (R^2 = 0.106, F (1,97) = 11.492, p = 0.001), (β = 0.358, t (97) = 3.390, p = 0.001).

Reason for Attending explained a significant proportion of the variance for three of the six outcome variables. The following represent the variance explained and effect sizes for each of these three statistically significant outcome variables: Mechanical Science Creativity (R^2 = 0.028, F (1,95) = 4.714, p = 0.054), (β = 0.341, t (95) = 1.955, p = 0.054). Science Relevance (R^2 = 0.155, F (1,93) = 17.000, p < 0.001), (β = 0.684, t (93) = 4.123, p < 0.001). And Self-Concept in Science (R^2 = 0.041, F (1,92) = 3.959, p = 0.050), (β = 0.374, t (92) = 1.990, p = 0.050).

Sociability did not explain a significant proportion of the variance for any of the six outcome variables.

As expected, only some Current Participant youth were classified as being in the better performing half (as measured in this study) of the four significant Potential Influence variables. In fact, only 12 of the 560 T1 participants, 2.1%, fell within the "high" categories of Out-of-School Experiences, Parental Attitudes, went to Camp Invention® for a learning reason, and had previously attended Camp Invention® at least two or more times prior to attending the current Camp Invention® program.

Post-Camp

Another series of Simple Regression models were conducted for the Past Participant group to investigate the effects that on-going Potential Influence variables had on Outcome variable scores. As with Current Participants, **Table 5** summarizes the results of these Simple Regression analyses for Past Participants on each of the six dependent variables–Mechanical Science Creativity, Creative Self-Efficacy, Science Relevance, Self-Concept in Science, Science Interest and Critical Thinking. As above, statistically significant differences (bold) in **Table 5** represent a positive difference between the High and Low Potential Indicator variables. In other words, the mean scores of the High group are significantly greater than the mean scores of the Low group.

Out-of-School Experiences explained a significant proportion of the variance for all six of the six outcome variables. The following represent the variance explained and effect sizes for each of these six statistically significant outcome variables: Mechanical Science Creativity (R^2 = 0.143, F (1,334) = 55.92, p < 0.001), (β = 0.579, t (334) = 6.605, p < 0.001). Creative Self-Efficacy (R^2 = 0.082, F (1,336) = 29.64, p < 0.001), (β = 0.500, t (336) = 6.101, p < 0.001). Science Relevance (R^2 = 0.198, F (1,336) = 82.80, p < 0.001), (β = 0.670, t (336) = 8.258, p < 0.001). Self-Concept in Science (R^2 = 0.112, F (1,336) = 42.32, p < 0.001), (β = 0.651, t (336) = 6.558, p < 0.001). Science Interest (R^2 = 0.096, F (1,336) = 35.85, p < 0.001), (β = 0.326, t (336) = 4.265, p < 0.001). And Critical Thinking (R^2 = 0.021, F (1,336) = 7.24, p = 0.003), (β = 0.186, t (336) = 3.019, p = 0.003).

Parental Attitudes also explained a significant proportion of the variance for all six of the six outcome variables. The following represent the variance explained and effect sizes for each of these outcome variables: Mechanical Science Creativity (R^2 = 0.087, F (1,336) = 31.83, p < 0.001), (β = 0.437, t (336) = 4.855, p < 0.001). Creative Self-Efficacy (R^2 = 0.107, F (1,336) = 40.06, p < 0.001), (β = 0.352, t (336) = 4.177, p < 0.001). Science Relevance (R^2 = *0.250,* F (1,336) = 111.81, p < 0.001), (β = 0.677, t (336) = 8.377, p < 0.001). Self-Concept in Science (R^2 = 0.132, F (1,336) = 50.83, p < 0.001), (β = 0.577, t (336) = 5.734, p < 0.001). Science Interest (R^2 = 0.039, F (1,336) = 13.73, p = 0.002), (β = 0.243, t (336) = 3.146, p = 0.002). And Critical Thinking (R^2 = 0.018, F (1,336) = 6.39, p = 0.030), (β = 0.135, t (336) = 2.175, p = 0.030).

Previous Camps did not explain a significant proportion of the variance for any of the six outcome variables.

Reason for Attending explained a significant proportion of the variance for five of the six outcome variables. The following represent the variance explained and effect sizes for each of these five statistically significant outcome variables: Mechanical Science Creativity (R^2 = 0.027, F (1,336) = 9.16, p = 0.002), (β = 0.289, t (336) = −3.093, p = 0.002). Creative Self-Efficacy (R^2 = 0.011, F (1,336) = 3.83, p = 0.048), (β = 0.174, t (336) = −1.980, p = 0.048). Science Relevance (R^2 = 0.044, F (1,336) = 15.70, p < 0.001), (β = 0.353, t (336) = −3.992, p < 0.001). And Self-Concept in Science (R^2 = 0.020, F (1,336) = 7.09, p = 0.008), (β = 0.287, t (336) = −2.686, p = 0.008).

Sociability explained a significant proportion of the variance for five of the six outcome variables. The following represent the variance explained and effect sizes for each of these five statistically significant outcome variables: Mechanical Science Creativity (R^2 = 0.026, F (1,336) = 8.96, p = 0.049), (β = 0.183, t (336) = 1.976, p = 0.049). Creative Self-Efficacy (R^2 = 0.039, F (1,336) = 13.56, p = 0.012), (β = 0.215, t (336) = 2.512, p = 0.012). Science Relevance (R^2 = 0.030, F (1,336) = 10.45, p = 0.002), (β = 0.271, t (336) = 3.097, p = 0.002). Science Interest (R^2 = 0.030, F (1,336) = 10.51, p = 0.002), (β = 0.245, t (336) = 3.172, p = 0.002). And Critical Thinking (R^2 = *0.081,* F (1,336) = 29.76, p < 0.001), (β = 0.255, t (336) = 4.174, p < 0.001).

As with Current Participants, only some Past Participant youth were classified as falling within the better performing half (as measured in this study) of the five Potential Influence variables. Twenty-two of the 352 TX participants, 6.3%, fell within the "high" categories of Out-of-School Experiences, Parental Attitudes, High Sociability, went to Camp Invention® for a learning reason, and had previously attended Camp Invention® at least two or more times prior to attending the current Camp Invention® program.

DISCUSSION

The goal of this exploratory research was to investigate whether it was possible to identify one or more non-Camp Invention®-related factors/variables–Potential Influence variables–which, in interaction with experiences occurring at Camp Invention®, might significantly contribute to 10 to 12 year-old youth's short and long-term changes in positive STEM-learning-related outcomes, in particular creativity, STEM interest, and problem solving. To achieve this, we collected and analyzed data from 10 through 12 year-old youth–with data collected prior to entering Camp Invention®, and two to three months after the conclusion of this camp experience. We also sampled groups of youth who had participated in this educational camp experience variously 1–4 years previously.

Importantly, as predicted, there was evidence that participation in one week of Camp Invention® resulted in statistically significant short-term improvements for some participating youth for some of the Outcome variables. In particular, measures of creativity and STEM interests. In the short-term, there was no evidence of significant improvements in problem-solving skills. Over the long-term, e.g., time periods of anywhere to 1–4 years post-Camp Invention®, there was strong evidence of significant growth in the three topic areas of creativity, STEM interest and problem solving (with the exception of Mechanical Science Creativity).

However also as predicted, although overall youth showed statistically significant improvements in their abilities in most of these three key educational areas, there was a distribution in the data. In other words, some youth showed considerable improvements in each of these three Outcome variables and some youth exhibited only small or no improvement.

Based upon the literature cited above, we hypothesized that a range of other non-Camp Invention®-related experiences, proclivities and factors–Potential Influences–might have contributed to this distribution of outcomes. Specifically, that depending upon either a youth's pre or post-Camp Invention® experiences or proclivities, that youth might end up having a more "successful" Camp Invention® experience than others. Accordingly, we created a series of survey items designed to assess, pre-camp and post-camp, the relative strength/presence of the following five Potential Influence variables:

- Out-of-School STEM Experiences (other than Camp Invention®)
- Parental Attitudes toward science and engineering
- Sociability (a personality measure of introversion vs. extroversion)
- Reason for Attending Camp (was the motivation related to content/learning or some other reason such as being with friends or parent made them go)
- Number of prior Camp Inventions® Attended (as a proxy for relevant prior experience and social capital).

Pre-Camp

There was evidence, that all of these Potential Influence variables did indeed have an effect on the educational Outcomes of Camp Invention®, although the influences were not uniform. Youth who had High levels of prior (non-Camp Invention®) out-of-school experiences showed greater growth across creativity and science interest educational Outcomes as compared with youth with limited or low prior (non-Camp Invention®) out-of-school experiences. Sociability did not appear to affect Camp Invention® educational Outcomes in the short-term, but emerges as an influence over the longer term. The other three pre-camp Potential Influence variables–parental attitudes, reason for attending camp, and prior Camp Invention® experiences–each influenced some of the six measured educational Outcome variables.

Specifically, the results suggested:

- For both creativity and STEM interest,—youth with considerable prior experience in learning STEM outside of school prior to entering camp appeared to benefit more from the Camp Invention® experience than did youth with limited or no such prior experiences.
- Youth who entered Camp Invention® with strong perceived parental support for learning about STEM appeared to be much more likely to show gains in STEM interest, as well as somewhat more likely to show improvements in creativity than did youth with lower levels of parental STEM support.
- Youth who went to Camp Invention® with the expectation that they would learn more about STEM, inventions, or creativity appeared to be much more likely to show gains in STEM interest, and to a degree, creativity than were youth who went to Camp because of other reasons.
- The knowledge, skills and/or social relationships that previous Camp Invention® experiences engendered appeared to be particularly important for enhancing creativity and problem solving as evidenced by the fact that youth with multiple, prior Camp Invention® experiences showed significantly higher gains in these areas than did youth with no or only limited Camp Invention® experience.

Also, important to note, was that only a very small fraction of youth, 2.1%, were in the better achieving half (as measured in this study) on all four of these key independent variables–Out-of-School Experiences, Parental Attitudes, went to camp for a learning reason, and had attended Camp Invention® at least twice before–and thus optimally pre-positioned to benefit from the Camp Invention® experience.

Post-Camp

There was even stronger evidence that all of these Potential Influence variables had a post-Camp effect on the educational Outcomes of interest to Camp Invention®. The results from this longer-term study suggested that over time, the interactions between these, and no doubt other variables, created strong influences on youth creativity, STEM interest, and problem solving. In the first study, which sampled a few months of a youth's life, the one-week Camp Invention® experience represented a relatively large, highly salient "dosage" of experience. In the longer-term study, which sampled on average several years of a youth's life, the one-week Camp Invention® experience represented a relatively small "dosage" of experience; albeit likely still a salient one.

Youth who had high levels of non-Camp Invention® out-of-school experiences consistently showed significantly higher levels of creativity, STEM interest, and problem solving than did youth with limited or low (non-Camp Invention®) out-of-school experiences. The same was also true for youth with high levels of perceived parental support. In this longer-term sample, more social youth also consistently showed significantly higher levels of creativity, STEM interest, and problem solving than did less social youth.

Specifically, the results suggested:

- Across two key areas of education outcomes related to entrepreneurship–creativity and STEM interest–youth with considerable and presumably on-going experiences in learning STEM outside of school appeared to be better able to build on their Camp Invention® experiences and sustain their gains in these three areas than did youth with limited or no such experiences.
- Youth who had strong perceived parental support for learning about STEM appeared to be much more likely than youth with low perceived parental support to be better able to build on their Camp Invention® experiences and sustain their gains in creativity, STEM interest, and problem solving.
- Youth who were more social appeared to be much more likely than less social youth to be better able to build on their Camp Invention® experiences and sustain their gains in creativity, STEM interest, and problem solving. [NOTE: This is a very provocative finding since it defies the stereotype of the introverted science geek.]

However, the fact that this variable did not emerge as significant in the short-term but did in the longer term makes it difficult to fully explain the role that sociability might be playing here and suggests the need for further exploration in the future.

- Youth who went to Camp Invention® with the expectation that they would learn more about STEM, inventions, or creativity appeared to be much more likely than were youth who went to Camp because of other reasons to maintain high levels of creativity and a strong STEM interest.

And just as in the earlier study, only a small fraction of youth, 6.3%, were "high" on all five of the Potential Influence variables tested–Out-of-School Experiences, Parental Attitudes, and (high) Sociability, went to camp for a learning reason, and had attended Camp Invention® at least twice before–and thus likely to optimally benefit from the contributions made by Camp Invention®.

Limitations

As with all social science research, this study had limitations that need to be acknowledged. The majority of the surveys were conducted online via links emailed to parents. As a consequence, participation was limited to children whose parent/caregiver had listed an email address with Camp Invention® and, after receiving the email, could access the internet. This clearly had the potential to bias the sample toward higher SES participants. Another potential bias was participant self-selection bias. Although we cannot know for sure whether those who self-selected to participate were disproportionately engaged and positive about their experience, it is fair to assume that this was the case. Given that the bottleneck in data collection was in getting longer-term data, i.e., the delayed post-test (T3) for the current campers and for all years of the long-term retrospective sample of youth (TX), it has to be assumed that some kind of self-selection was present in those who opted to respond to these longer-term surveys. Those who responded may have already been the most engaged and interested youth, though of course we have no way to know this for sure, and even if this was true, it is not clear how this bias would have impacted the major outcomes reported in this exploratory study.

The sample sizes for both data sets were smaller than the research team had hoped for, particularly the final short-term, immediate post-camp experience, thus limiting our ability to make generalizations. Limitations in sample sizes also required us to "lump" all of the long-term retrospective youth into a single population, despite the likely effects that developmental differences might have created, particularly in outcomes like self-concept.

In all studies of this nature, there are assumptions the measures one uses are valid and reliable indicators of the variables being considered, but of course this may or may not be the case. Since, by necessity due to the constraints of collecting data from youth within a free-choice context, the number of items used for each construct needed to be limited to increase the likelihood of survey completion, this too had the potential to reduce both validity and reliability.

Finally, due to the typical constraints of time and money, this effort only investigated a relatively modest number of Outcome variables and Potential Influence variables. There is no reason to believe that the particular variables selected for inclusion in this study represented either the most important outcomes possible from a STEM-related informal education experience nor the only influencing variables likely to result in significant effects, or even, after further study, would emerge as the most important influencing variables.

Implications

The above caveats notwithstanding, this study very successfully accomplished the goals it set out to achieve. From the start, this research was designed to be exploratory. Although the results presented are not definitive, and focused on only a single informal education experience, we feel comfortable stating that the findings are likely indicative of the tens of millions of youth who participate in informal STEM education programs annually around the world. In other words, the goal of this research was to explore the possibility that some learners, by virtue of their prior or subsequent experiences, proclivities, interests, and/or types of STEM-related support at home benefited more from a week-long informal education experience than did other learners. And if so, then it would suggest that these non-programmatic factors/variables are sufficiently important (i.e., have the potential to affect informal program learning outcomes) that informal education staff at this particular program, as well as potentially the staff of other similar types of programs, might want to think about how to accommodate, reinforce, support, and ameliorate these effects.

Based on the review of literature summarized above as well as the data gathered from these studies, we would hypothesize that the most cost-effective ways to improve the educational impact of informal education programs would be for educators to consider making modifications to their educational practices in one or some combination of the following three key areas:

1. Modifications in how children are prepared for participation in a program;
2. Changes to in-program experiences that allow for greater customization of experiences in order to better accommodate the differing needs and experiences of participating children; and
3. Implementation of strategies for proactively and mindfully supporting experiences post-program that both reinforce short-term changes in outcomes such as creativity, STEM interest, and problem-solving skills and also leverage opportunities to support these changes over time.

Below are some possible ideas for the kinds of changes in educational practice this research might suggest.

Modifications in Pre-Camp Preparation

Obviously, programs like Camp Invention® have only limited ways in which they can change the nature of youth prior to entering an informal education experience, but limited is not the same as none. A few suggested things informal education staff might consider doing are:

- Investing greater time and energy in helping youth think about how participation in their program might extend "learning-related" outcomes. Through pre-program materials, including potentially short YouTube videos, staff should work to reinforce how much fun learning about STEM, creativity and problem solving are likely to be–both during the experience, but equally prior and subsequent to the structured programmatic experience.
- Investing greater time and effort in helping parents know how critical is their support and encouragement for their child's learning. Obviously, getting a youth to participate in a program is an important indication of that support but so too is supporting youth at other times and even during the program period. Staff should develop and provide parents and caregivers with additional parent-learning tools designed to help parents know how to provide this kind of support on an on-going basis.
- Given that there appear to be additive and synergistic effects of multiple out-of-school STEM-related experiences, informal education providers should continue to find ways to partner with other STEM organizations that offer

out-of-school experiences and build ever-greater mechanisms for supporting each other's efforts.

Greater Customization of In-Program Experiences

One of the legacies of 20th century educational models was a tendency to create "one-size-fits-all" solutions–one set of programs that all children do. Research such as this suggest that more customized, individualized experiences better accommodate the differing needs and backgrounds of participating children and that individualization can potentially pay important educational dividends. A few possible ideas that informal science educators might consider are:

- Inclusion of a few diagnostic questions on pre-program materials that help alert program educators to dispositions and experiences of entering children/youth so that compensatory programming and opportunities can be developed.
- In general, providing more opportunities for children/youth to have some choice and control over the nature of their actual experiences. For example, although low vs. high sociability did not emerge as a consistently significant factor in determining learning outcomes, it did appear to be potentially an issue for some youth over the longer term. Given the current trend in education toward "group work," informal educators might want to explore ways to create more opportunities for youth to self-select whether they prefer to work by themselves or in a group, as well as have options beyond a "public presentation" for sharing with others what they have accomplished.
- Since it appears possible that youth with prior out-of-school and prior Camp Invention® experience disproportionately benefit from the informal experiences, informal education staff might try to think further about the relationship between these types of experiences. Is it that these children have a better ability to navigate the daily activities and schedules? Is it that they feel more comfortable with roles and relationships? Is it perhaps that they already understand something about the educational processes and pedagogical approaches that underlie the specific models used within a particular educational approach? If it could be figured out why these "advantages" seem important, then staff might be able to devise compensatory efforts to allow youth with less experience to more quickly get up to speed.

Supporting Post-Program Experiences

As with pre-program interventions, creating strategies for proactively and mindfully supporting long-term post-program experiences are not easy. Still, the evidence was compelling that on-going out-of-school experiences, parental support and even the bias toward extroverts appeared to reinforce informal education program-generated impacts on youths' creativity, STEM interest, and problem-solving skills. Some possible ideas for how to support these kinds of long-term engagement include:

- Since the data strongly suggested that multiple out-of-school STEM-related experiences have a significant additive and synergistic effect on youth creativity, STEM interest, and problem solving, informal educators should try to find ways to partner with other STEM-organizations that offer out-of-school experiences and collaborate and co-support each other's efforts.
- As above, given the evidence that perceived parental support is critical to sustaining the effects of informal education experiences, informal educators might consider how best to communicate this key information to parents and potentially even consider investing energy in supporting programming aimed at parents and care-givers as opposed to exclusively youth-focused programming, as is currently the norm.
- Given the preliminary evidence that multiple, prior experiences contribute to enhanced educational outcomes, particularly in the area of creativity, informal educators should explicitly and proactively communicate this to parents. They should tell parents that the benefits of participating in these experiences are not only significant but that there is evidence that such experiences appear to be additive–multiple experiences have the potential to result in significantly greater outcomes than a single experience. They should also communicate that other comparable experiences are also important, and that the more such experiences their children engage in, the greater is the likelihood that they will become STEM-motivated during adolescence and on into adulthood.
- The evidence for the effect of high sociability on long-term capabilities in creativity, STEM interest, and problem solving was, as noted above, quite provocative and worth thinking about how informal educations might create interventions that support youth who are less social than their peers. Perhaps follow-up experiences designed for individuals rather than groups could be developed and specifically targeted at youth identified as more introverted.

In conclusion, the goal of this hypothesis-generating research was to undertake a study to explore which, if any of a range of possible non-informal education experience-related factors/variables might significantly influence informal education program outcomes. Results suggest that a range of factors/variables do indeed appear to influence outcomes and that if thoughtfully and creatively addressed, might open up possibilities for significantly improved learning outcomes. Results also suggest that although informal education experiences are clearly impactful, currently significantly enhancing outcomes like creativity, STEM interest, and problem solving, there is still considerable room for improvement. Although efforts like the one studied in this particular research appear to be working well for the majority of participants, they appear to be only "optimally" working for a relatively smaller percentage of participants. As always, further research is required, but these findings appear to be sufficiently robust, provocative and actionable to warrant practitioners taking these results to heart and making immediate changes to their practice.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors if requested and justified.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Heartland Institutional Review Board, Swansea IL, United States. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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BRIEF RESEARCH REPORT
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A Moving Dune, A Stunning View: Visitors' Recollections of a Ranger-Led Hike at Indiana Dunes National Park

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Located 50 miles from Chicago, at Indiana Dunes National Park, thousands interact with rangers annually, many taking part in ranger-led hikes. The study focused on visitor recollections of a ranger-led hike that provided opportunities to learn about landscape change, recent events, and associated scientific findings. Interpreters are encouraged to co-construct audience-centered experiences, making space in interactions for visitors' knowledge, interests, and previous experience. Researchers observed six ranger-led hikes incorporating audience-centered design elements and recruited a convenience sample of twenty-one visitors for participation in a pre-hike survey to gather responses about interest and knowledge before the hike and their willingness to participate in a follow up post-hike phone interview. After ranger-led hikes, researchers conducted fifteen interviews using a phenomenological approach to glean visitors' recollections of the experience. Our findings confirm that visitors arrive with background knowledge, scientific interests, and curiosity. Months after the park experience, they were able to give examples of dune formation and change over time, the human effect on the landscape, and findings from recent events and scientific study at Mount Baldy. Interviewees recalled and reflected on rangers' facilitation and use of props, as well as visual details and feelings evoked by the physical conditions. The results offer a rare look at what sticks with visitors after their participation in a ranger-led hike.

Keywords: national parks, informal learning, visitors, STEM learning interest, STEM learning, interpretation

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INTRODUCTION

Interpretation in United States national parks has experienced significant changes in philosophy and practice in the 21st century. The interpreter's role had been envisioned as a guide (Mills, 1920), who "…reveals meanings and relationships" (Tilden, 2007, p. 33). National Park Service (NPS) interpreters have forged intellectual and emotional connections between visitors and the special places set aside for their historic significance, conservation and recreational value (Bacher et al., 2007). 21st century interpreters are expected to incorporate visitors' knowledge, interests, and previous experience (Knapp and Forist, 2014; National Park Service NPS, 2017). Interpreters can then take a constructivist approach to learning advocated by researchers in the field (Knapp and Benton, 2004; Copeland, 2006; Knapp, 2007; Knapp and Forist, 2014).

The ranger-led hikes studied at Indiana Dunes National Park were presented in concert with "Interpreters and Scientists Working on Our Parks" (iSWOOP), which aimed to increase science and visual literacy and STEM learning among visitors to United States national parks. iSWOOP equipped rangers with strategies to pique visitor interest in science behind the scenes and collections of still images, illustrations, figures, maps, and short video sequences (Allen et al., 2018). Props, stories, and visualizations can function as a portal for visitors in accessing the significance of the park (Knapp, 2007).

Park interpreters are part of an ecosystem that provides opportunities for place-based learning with potential impacts on visitors' engagement, knowledge, and interests (Friedman, 2008). Situational interest or momentary curiosity has been positively associated with attention and focus, comprehension and cognitive processing, memory and recall (National Research Council, 2009; Renninger and Su, 2012). As individuals become passionate about particular interests, they increasingly seek out other opportunities to learn, for example, by asking more curiosity questions or by visiting informal learning settings (Azevedo, 2013; Crowley et al., 2015).

Too little is understood about the dynamics of this type of free-choice learning in parks. The opportunity to analyze the knowledge and interests that park visitors enter a ranger-led experience with and what they recalled months later is rare. As explained by Storksdieck and Falk (2020), the roles visitors assume in their groups, motivations for visiting, and type of experience they seek out are even more varied in parks than in informal learning institutions with four walls and exhibits. Park visits can extend for days or weeks, potentially diluting or enhancing the impact of a particular learning opportunity. Furthermore, interests may be apparent only in a certain setting (Friedman, 2008) and triggered interests may be tangential to the intended focus or learning goals (Perry, 2002). Memories of place may eclipse memories of content (Forist, 2018). While recognizing these complexities, one can seek to understand what sticks with visitors after their participation in a specific activity. Recollecting, the act of retelling, is an indicator of learning (Friedman, 2008), common to interest and curiosity (Silvia, 2006). Thus we look at prior knowledge and interests in anticipation of, and recollections after a ranger-led hike, mindful that the experience is one element of a larger park visit.

In summer 2018, we conducted pre-hike surveys of visitors before and post-hike telephone interviews with them after ranger-led hikes on Mount Baldy at Indiana Dunes National Park, to understand the potential for STEM learning in national parks and what they recollect as memorable from that experience.

The Questions

Our questions emerged from a desire to support interpreters in delivering impactful, memorable STEM learning for park visitors. We sought to address these questions:

1. What scientific interests and knowledge do visitors begin their Mount Baldy hikes with?
2. What science content do visitors recall from their participation in an iSWOOP program at Mount Baldy?
3. What else do visitors recall about the ranger-led, iSWOOP-influenced experience?

METHODS

Positionality

The authors have backgrounds in science, education, and interpretation. All were actively conducting professional development and park-relevant research at the time of the study. The lead author attended six ranger-led hikes at Mount Baldy, greeting participants, acting as a participant observer, and as follow-up interviewer.

The Setting

In 1966 Congress placed 15,000 acres along Lake Michigan under the jurisdiction of NPS. Located just 50 miles from Chicago, millions have visited Indiana Dunes National Park (National Park Service NPS, 2020). The park is known for its great biodiversity; resource managers issue dozens of research permits annually.

Science Topics–Dune Formation and Change Over Time, Geology and a Near Death Experience

Mount Baldy presents unique opportunities for interpretation. In 2013 6-years old Nathan Woessner fell into a hole on Mount Baldy, which quickly filled in with sand (Sabar, 2014). After a successful rescue, NPS closed public access to Mount Baldy, where generations of children had enjoyed dune-sledding (Rowe, 2013). The accident precipitated new research (Argyilan et al., 2015). In 2017–2018, local geologist, Dr. Erin Argyilan, along with Dr. Todd Thompson and his colleagues at Indiana Geological & Water Survey, led hikes, gave presentations, and produced 3D models to strengthen the science content rangers presented to the public (See **Supplementary Video S1**; Czartorysky, 2018). Interpreters designed a multi-stop hike that emphasized key dynamics of the dune landscape that the public often misses. For example:

- Mount Baldy is a dune on a dune. The base dune is 3,000 years old.
- Wind patterns in combination with wave action and a jetty affect sediment deposition, deprivation, and erosion.
- The wind lifts fine grains of sand from the shoreline, which rise over and fall down the back side of the dune. This has caused the footprint of Mount Baldy to expand.
- Accounts of holes in dunes have not previously been documented by scientists.
- When buried, some trees are vulnerable to fungi-induced decay.
- The wind can remove sand, exposing cavities that were once buried trees, creating hazardous "dune decomposition chimneys" (Argyilan et al., 2015).

Participant Recruitment

Twenty-one adults from six different Mount Baldy hikes agreed to participate in the study (21 of 119 total visitors/17.6%).

Before the hikes began the researcher asked adult visitors if they would participate in a study on visitor experiences of ranger-led Mount Baldy hikes. Those responding affirmatively completed a brief pre-hike survey. All 21 granted permission to be contacted for a telephone interview. Visitors were promised anonymity and received an Indiana Dunes lapel pin as a token of thanks. Nearly three-quarters (15 of 21 or 71.4%) of those who agreed to participate in the study responded and were interviewed. This response accounts for 12.6% of hike attendees. Four attempts were made by email and telephone to contact the remaining individuals, with no success.

Pre-Hike Survey Instrument

The pre-hike survey included five questions: two probed visitors' scientific interests about Mount Baldy; one asked about prior knowledge; one asked their reasons for participating, and one elicited contact information for a phone interview. No demographic data were collected. The open-ended questions reported on include:

- What do you currently know about Mount Baldy?
- What scientific interest do you have regarding Mount Baldy?
- What are you interested in learning about Mount Baldy during today's hike?

Post-Hike Interview Instrument

Telephone interviews were conducted between 3 and 8 months after the person's park visit. A phenomenological approach was used to investigate participants' recollections of the interpretive experience, seeking clarification and understanding of people's perceptions and experiences, especially the meanings they give to events, concepts, and issues (Mabry, 2000). The interviews were open-ended, beginning with the question, "Can you please tell me about your Mount Baldy hike?" This choice was made to avoid establishing an initial bias toward recollections about the interpretive aspects of the hike. Prompts were based on interviewees' comments. For example, if the interviewee mentioned buried trees, the interviewer said: "Can you tell me more about the buried trees?" The majority were 10–15 min in duration.

Coding Pre-Hike Survey

Two researchers agreed upon code categories and checked their ability to apply the codes independently using the Dedoose qualitative data software (Lieber, 2020). Numerous codes were used for the existing knowledge question. Emergent themes in the other data led to three general categories describing visitor interest: 1) Curiosity to Learn; 2) Importance of Place; and 3) Outdoor Activity.

Coding the Post-Hike Interviews

Interviews were recorded and transcribed verbatim. Transcriptions were analyzed using Dedoose (Lieber, 2020). Researchers counted each time interviewees gave a response to a question or prompt as one comment, whether it was a word, a sentence, or several paragraphs in length. As described above, two researchers worked together creating and checking their ability to apply codes. From the 15 interviews, we garnered 214 comments initially coded as "impacts of the hike." Specific categories of recalled impacts were then determined to be: 1) Learning about Park; 2) Enjoyment of Park; 3) Appreciation of Ranger; and 4) Sharing the Experience (with others afterward). The greatest bulk of responses to the post-hike interviews fell into the recalled Learning about the park category. For this reason, data were further refined and coded according to topics of new learning including 1) Generally the Park; 2) Dune Formation and Change; 3) Park Stewardship; and 4) Technology.

RESULTS

We describe results from two datasets. First the pre-hike survey—of visitors' scientific interests and knowledge—we gathered 118 statements (responses to three open-ended questions) from 21 participants. We then describe visitors' recollections of their ranger-guided Mount Baldy hike using data collected from open-ended telephone interviews with 15 of the original 21 study participants. Analysis of 151 distinct statements from the 15 participants focuses on their recall of scientific content and discoveries, visual details of props and landscape elements from their hike, and ways they reflected on or shared their hike after their park visit.

Pre-Hike Surveys

In 21 pre-hike surveys, respondents offered 34 discrete statements about existing visitor knowledge (**Figure 1**). Half of the responses indicated some knowledge about the formation and movement of sand dunes over time (17 of 34 responses/50%). Just over one quarter of responses were about the accident in 2013 that led to Mount Baldy's closure (9 responses/26.5%): five of those responses (14.7%) referred to the 2013 accident while four responses (11.8%) referred to the area's closure. Another few listed some knowledge about natural history or ecology (4 responses/11.8%), past knowledge or personal connection to Mount Baldy (4 responses/11.8%) environmental protection and stewardship (1 response/2.9%) or the view from Mount Baldy (1 response/2.9%). We therefore concluded that 50% knew little about dune movement and change and close to 75% knew few if any specifics about the 2013 accident.

Reporting visitor interest, 84 discrete responses were offered (**Figure 2**). The majority were a reflection of their wanting to know/Curiosity to Learn (73 of 84 responses/86.9%). These included general interest, e.g., "this looked interesting," and those with more defined lines of interest, such as "interested in sustainability in national parks," or "to gain appreciation for different natural features of the country". Visitors expressed curiosity very specifically, wondering, "What made these dunes".

Just over a tenth of the responses revealed their wanting to see/Importance of Place as an interest (10 of 84 responses/11.9%). Responses included interests in visiting Indiana Dunes or an NPS site, visiting a closed area, revisiting a place that held a personal or

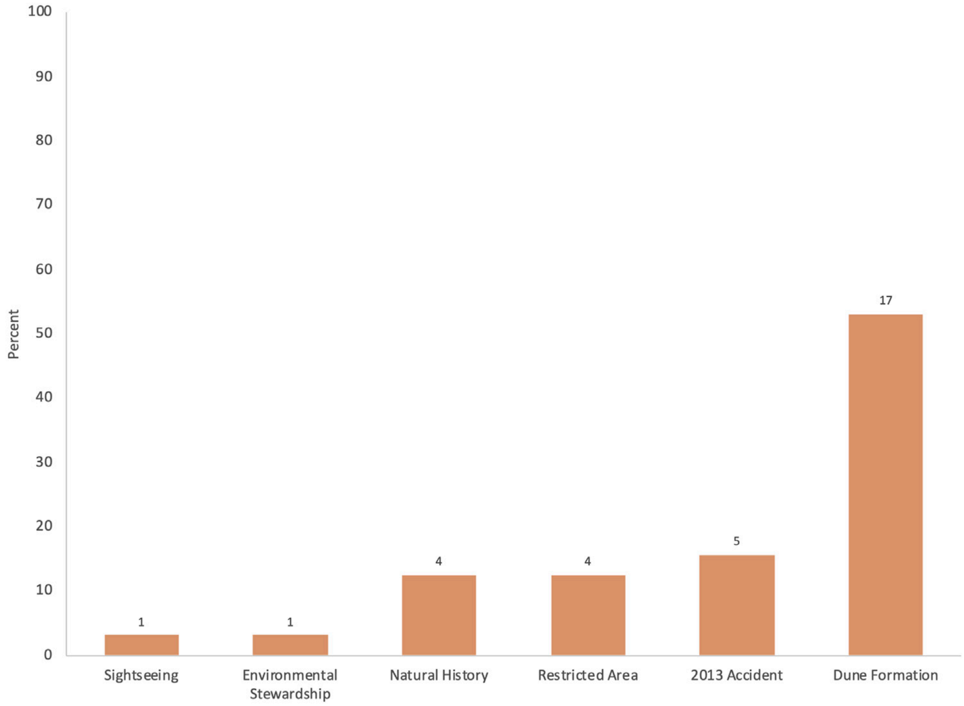

FIGURE 1 | Visitor knowledge prior to Mount Baldy hike (*n* = 34).

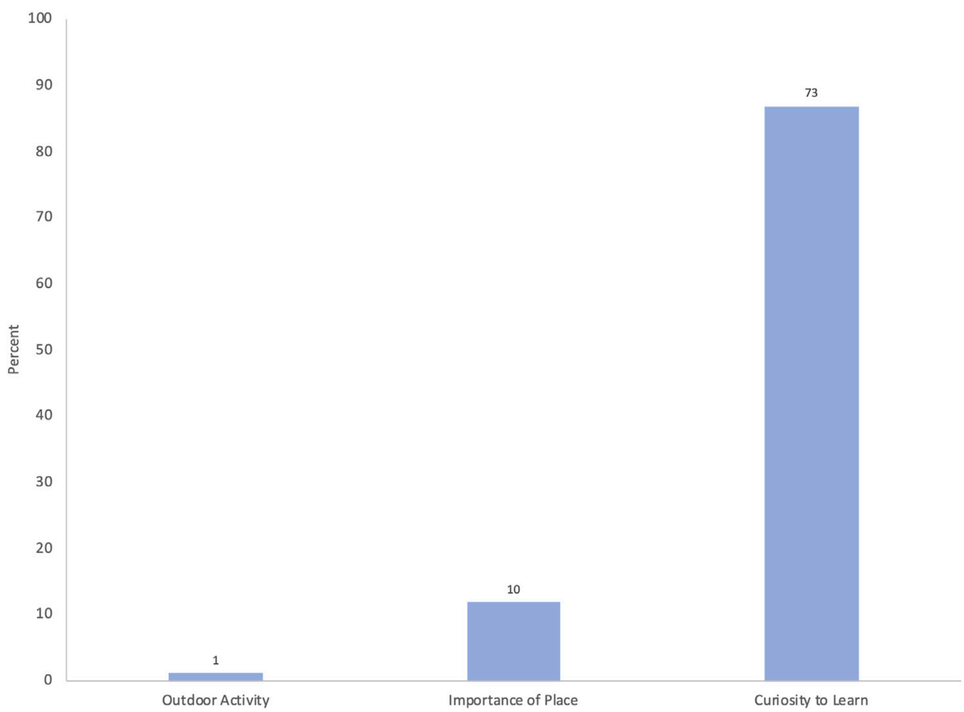

FIGURE 2 | Visitors interest prior to Mount Baldy hike (*n*-84).

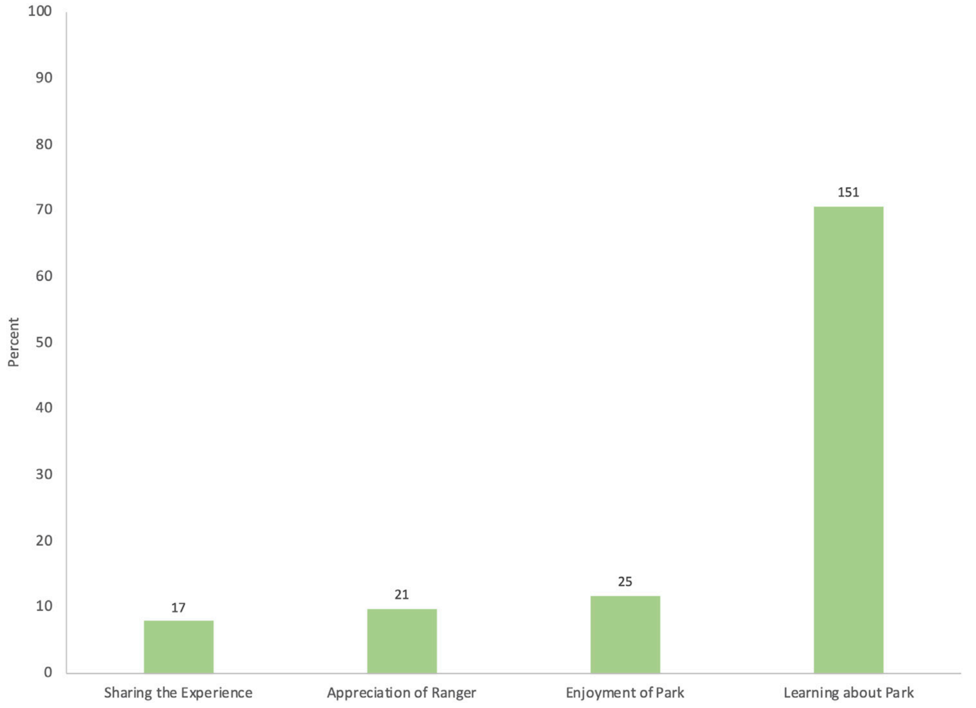

FIGURE 3 | Impacts of hike recalled by visitors (n = 214).

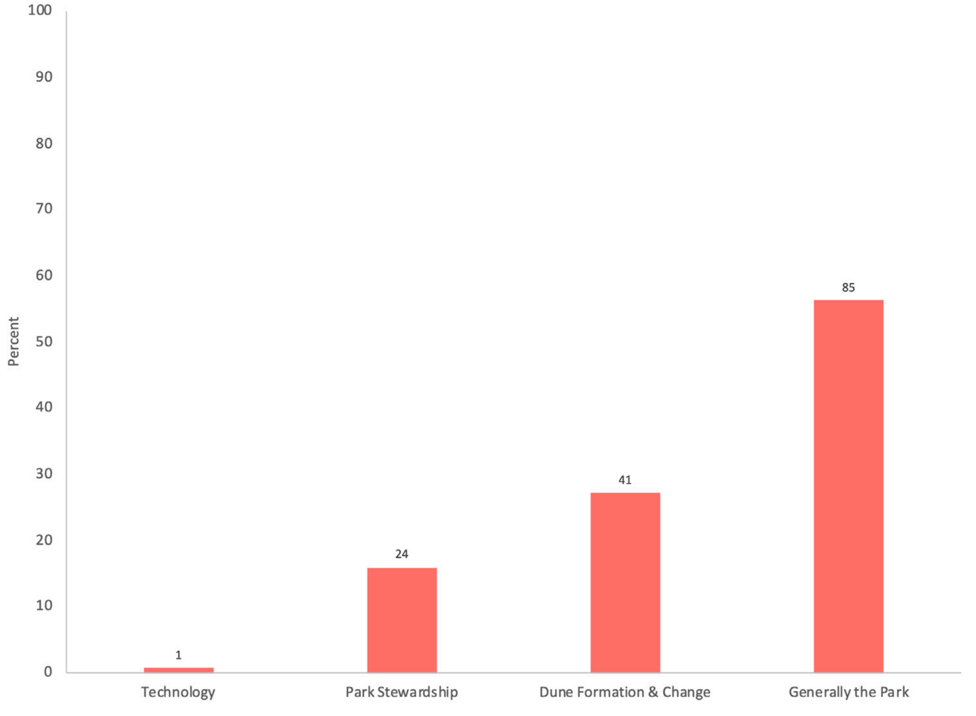

FIGURE 4 | Science content recalled from Mount Baldy Hike (n = 151).

family connection, or an interest in enjoying the view. These were all seen as indicators of the importance that particular place had in the visitors' decision to join a Mount Baldy hike. Just one response (1.2%) indicated interest in their wanting to do/Outdoor Activity.

Post-Hike Interviews

Data from the open-ended telephone post-hike interviews illuminated impacts of the hike as aspects of the ranger-led experience that were memorable and recalled by respondents (**Figure 3**). A total of 214 statements were drawn from the interview transcripts. Nearly three quarters of these (151 of 214 or 70.6%) fell within the Learning about Park category describing recalled knowledge from the hike. Data reflecting specific topics of recalled learning were further categorized and will be elaborated upon below. The balance of responses (63 of 214/29.4%) were about recalled Enjoyment of Place (25/ 11.7%), recalled Appreciation of Ranger(s) leading the hike (21/ 10.0%), or recalled Sharing of the Experience with others after their Mount Baldy hike (17/7.9%).

CONTENT LEARNING RECALLED ON THE RANGER-LED HIKE

Recollections coded as recalled Learning about Park are further categorized by topics of recalled learning (**Figure 4**). More than half, 85 comments (56.3%) were coded as recalled learning about Generally the Park (for example, visitors referred to off-trail hikers trampling plants). More than a quarter of the responses demonstrated recalled learning about Dune Formation and Change (41 of 151/27.2%). Twenty-four visitor (15.9%) comments referred to recalled learning about Park Stewardship. One response (0.7%) indicated recalled learning about Technology.

Beyond the categories of learning recalled as noted above, sub-themes emerged that, in some cases, were revealed in more than one of the categories below.

Recalled Learning About the Park and Dunes: Dune Formation and Change

The various phenomena related to dune formation and change arose as a significant element of the Mount Baldy hike. Interviewees were forthcoming with explanations for the changing shape of the dune. Many statements highlighted human impacts related to dune formation and change. For instance, five of the responses in this category mentioned the Michigan City jetty that has trapped sand on its eastern side, preventing accretion of new sand to replenish Mount Baldy. While the pre-hike survey indicated that the majority of interviewees had no prior knowledge of the nearly fatal 2013 accident, 14 out of 15 interviewees explained details of the boy who fell into a hole in Mount Baldy, his rescue, and the geological study that it precipitated. Connecting dune formation and change over time with recent scientific findings and that accident, one interviewee recalled:

> It was just that it was formed by trees that had been consumed by the dune. And I think there were some other processes, some fungus or something that was inside the trees that kind of made the outside of the trees stay intact so that the inside of them was not, not sand. And that's what made the hole.

Recalled Learning About the Park and Dunes: Parks as Outdoor Labs

Recent studies and scientists' methods were mentioned in some interviews. Two visitors mentioned that scientists employed technologies to investigate the holes in the dune (ground penetrating radar, laser scanning, and core samples), although more referred to scientists' methods generically, e.g.,"scans" and "radio graph". Recollections of the research flowed into recollections of the reasons for restricted access to Mount Baldy.

> And she had said there'd been a lot of research after that with some kind of. . .I thought they'd mapped out where all the holes were not determined, where we were really able to go on the dunes.
>
> . . . We learned that before the dune was there, it was trees and shrubs and just like greenery and then over time as the dune formed to cover all that up and of course without some light, all that stuff died and started to decay over time and eventually leading to soft spots and why we can't walk on the dunes today.

Recalled Learning About the Park and Dunes: Parks and Their Contexts as a Topic of Interest

Visitors articulated their interest in national parks and mentioned ways they sustained it, for example, by following parks, seeking information, planning travel, and talking with others about what they enjoyed. Eight respondents reported sharing their experience with family and friends after their visit. One stated,

> I am from North Carolina...you know, people that are from the Smoky Mountains, . . . they do not know Indiana has the dunes. . . . I showed people that I work with, "Look at these dunes; it is amazing" A lot of people had no idea.

Another interviewee said, " . . . *Been to a few national parks over the past year, which has been really exciting . . . you just learn such a vast amount of information ....*" Five interviewees spoke explicitly about experiences with rangers in other parks.

One interviewee mentioned the ranger's influence on their experiences after their guided hike:

> . . . Even yesterday I was out in Miller Woods and I see...these low lying pools of water. It makes me think, "Ha, is this from the recent receding glaciers? What is this area all about?" . . . And so, I stop and I will read the

> information, because I had such a good experience with what she was saying and (that) promotes me to think.

MEMORABLE ELEMENTS OF HIKE

Interviewees mentioned the weather, the terrain and duration of the hike, as well as the view, which made an impression on them.

> I mean it's. . .the high point in the dunes. So that's the coolest stuff and the stunning view from the top.
>
> Well, I recall I enjoyed it quite a bit. I mean it was a great view. ... There was some tough parts getting up there...that was a climb. But. . .got some great photos and, and my son really loved being up there and. . .learned a lot about the dune . . .the holes that are being created and that sort of thing.

Included in visitor interviews were their recollections regarding interpretive elements of the Mount Baldy hikes. Just over 15% (33 of 210/15.7%) referred to demonstrations by the rangers. The majority of these (21 of 33/63.6%) were images or models. Rangers held up and passed around laminated images, displayed 3D models that some visitors touched, and sand sorters, one of the scientific tools geologists use. These props and visuals made an impression.

> I think that those (models) were an easy way of understanding what they actually meant when they said that the shape of the sand dunes have changed .... You are seeing that and like actually showing it to me. I think that makes you remember it for longer.

In a smaller proportion of cases (12 of 33 or 36.4%), the rangers demonstrated elements of the natural or built environment to emphasize points in the Mount Baldy story.

> I think that the biggest, well kind of physical tool, the fence, the barrier, that "don't climb on the sand dune"...at the parking lot. That was going to be in your face like, right up front. . .The first thing you realize is, wow, the dune is right here in the lot, it's coming this way.

In sum, interpreters delivered a multi-stop, multisensory experience of Mount Baldy. While visitors originally claimed some knowledge on their pre-hike surveys, they were able to provide details in their post-hike interviews that they had not included on pre-hike surveys. We found an interest in and detailed recall of the changing dynamics of dunes and sand, of the 2013 accident which precipitated restricted use as well as new research findings, along with emotional, physical, and social memories of the experience. At times visitors were vague on details, labored to remember, or seem to have misremembered details. Such responses were not a focus of this study.

DISCUSSION

Our questions centered on visitors' pre-hike knowledge and interests and their post-hike recollections. Visitors to parks have their own agendas and, particularly in immersive experiences, may attend to their family members and the surroundings as much as to the interpreters (Falk, 2009). Without the need to apply the information, it is reasonable to expect that months after a ranger-led hike, details of the scientific content covered might be vague. Previous studies have shown that the actual interpretation offered fades, eclipsed by memories of the place itself (Forist, 2018). iSWOOP's professional development is designed to make science communication in parks memorable through the use of arresting visuals, stories of how scientists know what they know, and opportunities for interaction. While we conjectured that the story of holes in Mount Baldy leading to new understandings of dune and tree interaction would make an impression, we were not predicting that visitors would have detailed recall of the dynamics of dune formation and change. Nonetheless, pre-hike surveys and post-hike interviews yielded a data set that paints a rich picture of the lasting impression left on a subset of visitors participating in Mount Baldy hikes.

Visitors arrived at the hike wanting to learn more about the history of the site, human impacts, and the park's plan for access. In interviews, visitors had much to say about these topics (nearly three-quarters of 214 interview statements referred to knowledge recalled from the hike) confirming findings from research in other out-of-school settings showing that people have greater motivation to engage and learn if the subject matter is directly relevant to their interests and/or if the learning process is interactive (Falk, 2001). Specifics of the rangers' pedagogical moves, e.g., displaying 3D models and leading an enactment of erosion, were memorable to a number of participants. Participants' comments affirmed findings on positive associations with props (Knapp and Benton, 2005; Stern et al., 2012) and their appreciation of rangers including ranger passion, leadership, and knowledge (Forist, 2003; Knapp, 2007). Four visitors made specific comments about the value they found in the rangers; knowledge. With five different rangers leading the observed hikes, it is not surprising that opinions and recollections were varied, with some highly appreciative of the rangers and impressed by their knowledge while others were neutral.

As noted previously, it has been recommended that interpreters follow a constructivist framework—an educational approach based in direct interactions between the learner and teacher, or in parks, the interpreter and the visitor (Copeland, 2006; Knapp, 2007; Black, 2012). As developed by Bruner (1966), constructivism is a process through which actively engaged learners (or visitors) construct new knowledge based upon their past knowledge in the context of new experience. In such a case, the interpreter's role is more that of a facilitator than an instructor and the visitor is engaged rather than instructed (Knapp, 2007; Whisnant et al., 2011). In this study, the relationship between visitor knowledge and interest as reported on our pre-hike survey and the outcomes of the telephone interviews might be thought of as reflecting new knowledge constructed. The prominence of acquired knowledge reported during interviews (151 of 214 or 70.6% of all coded responses) indicates new knowledge. This, combined with the frequency that visitors reported their prior knowledge being utilized by rangers leading the Mount Baldy hikes (68 of 210 or 32.4% of comments regarding interpretive elements in the hikes), provides some evidence of a positive effect in applying a constructivist approach to interpretation. Further study is needed, looking at outcomes of an experience like the Mount Baldy hike in the context of pre-hike visitor interest and knowledge along with detailed analysis of constructivist elements included in hike delivery.

Ultimately, informal educators (and our funders) want to know to what extent ranger-led hikes are useful in sparking interests and effective as catalysts for knowledge gain? Based on this study, we can say that when visitors' curiosity and lines of interest align with the content delivered along with striking visuals, visitors' recollections were rich in detail. That visitors shared aspects of their experience with friends and family after their park visit is an indicator of knowledge acquired and continued interest in the park resources and features. Direct testaments to new interests sparked by the scientific content (joining a group, acquiring new books), were not offered during these interviews. Yet we know that visitors' interests may lie dormant for months, become an enjoyable focus when travelling or a seasonally limited opportunity opens.

The dataset for this study provides opportunities for further learning. We expect to take a deeper look at individual profiles to understand implied connections between visitors' expectations and their recollections. In future studies we would like to explore this relationship between experience input (visitors' existing knowledge and interest), application (interpretive techniques or methods), and output (visitor recollections). We would like to describe the relationship between interpretive methods employed (beyond the visuals, tools, and props reported on here) and visitor recall.

We hope future research could investigate the impact of the study methods on recall. For example: Does the act of writing down a question pre-dispose visitors to the ability to recall details? Does the anticipation of an interview about a past experience activate stored knowledge? Do visitors prepare once a follow-up interview is scheduled? If these interventions make STEM learning stick, can such techniques be intentionally used by interpreters?

CONCLUSION

Salient findings confirm that visitors arrive for guided experiences in parks with background knowledge, scientific interests, and curiosity. They have a desire to know, to see, and to do. Months after the park experience, interviewees were able to recall scientific knowledge and give examples of dune formation and change over time, the human effect on the landscape, explain the park staff's reasoning for area closures, and share details of the scientific study that led to new interdisciplinary findings. Participants of the hikes recalled visual details (such as the sand dune moving overtaking the parking lot), emotional responses (savoring a stunning view), physical feelings (successfully climbing the dune), and reflected on rangers' facilitation and use of props. This qualitative study provides insights for park leaders, interpreters and informal and STEM educators, affirming that ranger-led programs using visualizations, props, and dramatic stories as a vehicle for increasing knowledge and interest about humans' impact and landscape change were elements of visitors' recollections.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by TERC Internal Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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SUPPLEMENTARY MATERIAL

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Addressing the Ceiling Effect when Assessing STEM Out-Of-School Time Experiences

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The aim of this paper is to describe an analytical approach for addressing the ceiling effect, a measurement limitation that affects research and evaluation efforts in informal STEM learning projects. The ceiling effect occurs when a large proportion of subjects begin a study with very high scores on the measured variable(s), such that participation in an educational experience cannot yield significant gains among these learners. This effect is widespread in informal science learning due to the self-selective nature of participation in these experiences, such that participants are already interested in and knowledgeable about the content area. When the ceiling effect is present, no conclusions can be drawn regarding the influence of an intervention on participants' learning outcomes which could lead evaluators and funders to underestimate the positive effects of STEM programs. We discuss how the use of person-centered analytic approaches that segment samples in theory driven ways could help address the ceiling effect and provide an illustrative example using data from a recent evaluation of a STEM afterschool program.

Keywords: ceiling effect, informal STEM learning, evaluation, person-centered analysis/approach, out-of-school activities

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INTRODUCTION

As concerns arise about the need to increase the number of US STEM professionals in order to remain globally competitive, the pressure to emphasize STEM education particularly for adolescent youth has never been greater. Many educators and researchers recognize an urgent need to identify strategies for developing youth skills, abilities and dispositions in STEM early in life, particularly for underserved youth, to increase the potential for future academic and professional participation in STEM fields (National Research Council, 2010).

Out-of-school time (OST) activities such as afterschool programs, summer camps, and other enrichment programs (e.g., Girl Scouts science clubs) are uniquely situated to address this need with their ability to reach large numbers of young people, including low-income youth and youth of color (Afterschool Alliance, 2014). While schools often focus on delivering STEM content knowledge and science process skills National Research Council (2012a), OST programs emphasize the fostering or development of affective and emotional outcomes, such as STEM interest and identity, that are strongly associated with STEM persistence and increased future academic and professional participation in STEM fields (National Research Council, 2009; Maltese and Tai, 2011; Venville et al., 2013; Maltese et al., 2014; Stets et al., 2017). However, evaluating the success of such programs can be problematic due to the variable, unstructured nature of informal learning environments themselves, as well as the fact that participants often self-select programs based on their prior interests (National Research Council, 2009). Thus, although some studies have documented significant cognitive and affective gains from participation in out-of-school STEM activities such as science clubs Bevan et al. (2010), Stocklmayer et al. (2010), Young et al. (2017), Allen et al. (2019), many others, particularly smaller programs with fewer participants, have failed to document significant increases for participants as a whole (Brossard, et al., 2005; Falk and Storksdieck, 2005; Judson, 2012).

The most likely reason for this phenomenon is the presence of a measurement limitation called the ceiling effect which can occur when a large proportion of subjects begin a study with very high scores on the measured variable(s), such that participation in an educational experience cannot yield significant gains among these learners (National Research Council, 2009; Judson, 2012) This effect is often attributed to the biased nature of participation. Informal science learning opportunities, including after school programs, are particularly susceptible to this effect due to the fact that participants generally choose to participate because they are already interested in and potentially knowledgeable about the content area. When the ceiling effect is present, no conclusions can be drawn regarding the influence of an intervention for youth *on average*. This effect can hinder efforts to evaluate the success of a program by leading evaluators to underestimate the positive effects on affective or cognitive learning outcomes that are measured with standard instruments.

In this paper we describe how person-centered analytic models could help informal science evaluators and researchers address the ceiling effect while potentially providing a better understanding of the outcomes of participants in ISL programs and other experiences. We refer to person-centered analytic models as approaches to data analysis that distinguish main treatment effects by participant type in meaningful (i.e., hypothesis-driven) ways. Although used frequently in other fields such as educational psychology, sociology, and vocational behavior research, person-centered analyses are still fairly uncommon in informal science education research and evaluation (Denson and Ing, 2014; Spurk et al., 2020). We begin with a short discussion of the ceiling effect in OST programs and the affordances and constraints of person-centered approaches as compared to more traditional variable-centered models for analyzing changes in outcomes over time. To further clarify the methodologies, we then provide an empirical example in which each type of approach is used on the same data set from the authors' evaluation of 27 afterschool STEM programs in Oregon Staus et al. (2018) in which the usefulness of the person-oriented approach and the variable-oriented approach are compared.

LITERATURE REVIEW

Out-Of-School-Time Programs

Out-of-school-time (OST) programs are a type of informal STEM learning opportunity provided to youth outside of regular school hours that include afterschool programs, summer camps, clubs, and competitions (National Research Council, 2009; National Research Council, 2015). OST programs provide expanded content-rich learning opportunities, often engaging students in rigorous, purposeful activities that feature hands-on engagement, which can help bring STEM to life and inspire inquiry, reasoning, problem-solving, and reflecting on the value of STEM as it relates to children and youth's personal lives (Noam and Shah, 2013; National Research Council, 2015). In addition, OST STEM activities may allow students to meet STEM professionals and learn about STEM careers Fadigan and Hammrich (2004), Bevan and Michalchik (2013), and can help learners to expand their identities as achievers in the context of STEM as they are actively involved in producing scientific knowledge and understanding (Barton and Tan, 2010).

Another key aspect of OST STEM time is that it is generally not associated with tests and assessments, providing a space for children and youth to engage in STEM without fear and anxiety, therefore creating a psychologically safe environment for being oneself in one's engagement with STEM. In fact, it is the non-assessed, learner-driven nature that makes OST engagement ideal for fostering affective outcomes around interest, identity, self-efficacy, and enjoyment (National Research Council, 2009; National Research Council, 2015). Consequently, many OST programs promote a number of noncognitive, socio-emotional learning (SEL) skills such as teamwork, critical thinking and problem-solving (Afterschool Alliance, 2014). Also known as twenty-first century skills, these skills are seen as essential to many employers when hiring for STEM jobs. Thus, participation in OST programs could potentially positively affect youths' later college, career, and life success (National Research Council, 2012b).

Despite the strong potential for OST programs to provide positive benefits to participants, there have been few studies that document significant changes in outcomes for youth as a result of participation in these programs (Dabney, et al., 2012; National Research Council, 2015). One recent study utilized a mixed-methods approach including surveys and observations of over 1,500 youth in 158 STEM-focused afterschool programs to investigate the relationship of program quality on a variety of youth outcomes and found that the majority of youth reported increases in STEM engagement, identity, career interest, career knowledge, and critical thinking (Allen et al., 2019). The largest gains were reported by youth who engaged in longer-term (4 weeks or more) and higher quality programs as measured with the Dimensions of Success (DoS), a common OST program assessment tool.

Similarly, using a meta-analysis of 15 studies examining OST programs for K-12 students, Young et al. (2017) found a small to medium-sized positive effect of OST programs on students' interest in STEM, although the effect was moderated by program focus, grade level, and quality of the research design. For example, programs with both an academic and social focus had a greater positive effect on STEM interest, while exclusively academic programs were less effective at promoting interest in STEM. The authors found no significant effect for programs serving youth in K-5; all other grade spans showed positive effects on STEM interest. Unlike Allen et al. (2019), this study found no effects related to the duration of the programs.

In contrast to the above large-scale research projects, many researchers or evaluators have failed to document significant increases in STEM outcomes for OST program participants as a whole. In particular, evaluations of single OST programs with fewer participants may have difficulty showing significant changes in STEM outcomes as a result of participating in the program. For example, an evaluation of a collaboration between libraries, zoos and poets designed to use poetry to increase visitors' conservation thinking and language use, found few significant changes in the type or frequency of visitor comments related to conservation themes or in their thinking about conservation concepts (Sickler et al., 2011). Similarly, in an evaluation of 330 gifted high school students participating in science enrichment programs, evaluators found no positive impact on science attitudes after participation in the program (Stake and Mares, 2001). Although mostly serving adults rather than children, several citizen science projects reported similar difficulty in documenting significant positive outcomes for participants (Trumbull et al., 2000; Overdevest et al., 2004; Jordan et al., 2011; Crall et al., 2012; RK and A, Inc., 2016). For example, an evaluation of The Birdhouse Network (TBN), a program in which participants observe and report data on bird nest boxes, revealed no significant change in attitudes toward science or understanding of the scientific process (Brossard et al., 2005). It is likely that there are many more examples that we were unable to access since program evaluations in general and studies that fail to find significant results in particular, often do not get published.

One plausible explanation for the lack of significant results in program-level evaluations like those described above is not that these programs failed to provide benefits to their participants, but that at least in those with significant positive bias in the participants, the presence of a ceiling effect resulted in a lack of significant gains among these learners on average (National Research Council, 2009; Judson, 2012). For example, in the TBN citizen science study mentioned above, participants entered the program with very strong positive attitudes toward the environment such that the questionnaire used to detect changes in attitudes was insensitive for this group (Brossard et al., 2005). As described earlier, the ceiling effect is a common phenomenon in OST programs which often attract learners who elect to participate because they are already interested in and knowledgeable about STEM (Stake and Mares, 2001; National Research Council, 2009). The potential danger of the ceiling effect is that positive outcomes due to participation in the OST program may go undetected when measured by standard measures which could lead to funding challenges or even termination of a program. Therefore, it is critical that program evaluators utilize appropriate analytic approaches that account for the ceiling effect to better understand how OST programs influence learner outcomes.

Analytic Approaches

Historically, the most common analytic methods when evaluating OST programs have involved a pre-post design using surveys administered at the beginning and end of the program to measure changes in knowledge, attitudes, and similar outcomes, presumably as a consequence of the educational experience (Stake and Mares, 2001). The pre-post data are typically analyzed with a variety of variable-centered approaches such as t-tests or ANOVAs to examine changes in outcomes of interest (e.g., content knowledge, attitude toward science) over the course of the program. However, as described above, the traditional pre-post design may be insufficient for measuring the impact of intervention programs when many participants begin the program with high levels of knowledge and interest in STEM topics and activities. This is because variable-centered analytic models produce group-level statistics like means and correlations that are not easily interpretable at the level of the individual and do not help us understand how and why individuals or groups of similar individuals differ in their learning outcomes over time (Bergman and Lundh, 2015). In other words, if subgroups exist in the population that do show significant changes in outcomes (perhaps because they began the program with lower pre-test scores), these results may be obscured by the use of variable-centered methods.

In contrast, "person-centered" analytic models are predicated on the assumption that populations of learners are heterogeneous, and therefore best studied by searching for patterns shared by subgroups within the larger sample (Block, 1971). Therefore, the focus is on identifying distinct categories or groups of people who share certain attributes (e.g., attitudes, motivation) that may help us understand why their outcomes differ from those in other groups (Magnusson, 2003). Standard statistical techniques include profile, class, and cluster analyses, which are suitable for addressing questions about group differences in patterns of development and associations among variables (Laursen and Hoff, 2006). However, because of the "regression effect" (i.e., regression to the mean) phenomenon in which those who have extremely low pretest values show the greatest increase while those who have extremely high pretest values show the greatest decrease Chernick and Friis (2003), subgroups must be constructed from variables other than the outcome score being measured. In addition, the selected variables that form the groups must have a strong conceptual basis and have the potential to form distinct categories that are meaningful for analyzing outcomes (Spurk et al., 2020). In the case of OST programs, one such variable may be motivation to participate.

Substantial research shows that visitors to informal STEM learning institutions such as museums, science centers and zoos arrive with a variety of typical configurations of interests, goals, and motivations that are strongly associated with learning and visit satisfaction outcomes (Falk, 2009; Packer and Ballantyne, 2002). Moussouri (1997) was one of the first to identify a typology of six categories of visitor motivations including education, social event, and entertainment, two of which (education and entertainment) were associated with greater learning than other motivation categories (Falk et al., 1998).

Packer (2004) expanded on this work in a study of educational leisure experiences including museums and interpretive sites, in which she identified five categories of visitor motivations: 1) passive enjoyment; 2) learning and discovery; 3) personal self-fulfillment; 4) restoration; and 5) social contact; only visitors reporting learning and discovery goals showed significant learning outcomes. Since then, numerous informal STEM learning researchers have used audience segmentation to better understand the STEM outcomes of visitors (e.g., Falk and Storksdieck, 2005; Falk et al., 2007; O'Connell et al., 2020; Storksdieck and Falk, 2020). These studies suggest that learning outcomes differ based on learner goals or motivations, supporting the potential usefulness of this variable for person-centered analyses in informal science research and evaluation, including OST programs for youth.

In the case of OST programs, children also participate for a variety of motivations including interest in STEM, to socialize with friends, to have fun, and because they are compelled by parents. Thus, person-centered approaches could be used to identify subgroups of participants with differing motivations for participating in the program that may affect their identity and learning outcomes. Then variable-centered analyses such as t-tests could be used to examine changes in outcomes for each subpopulation. To help clarify how the person-centered methodologies described above could address the ceiling effect problem, we provide an illustrative example in which each type of approach is used on the same data set from the authors' prior research and the findings from the person-centered approach and the variable-centered approach are compared.

Component	Definition
Learner Identity	Youth see themselves as succeeding in learning and working environments emphasizing science.
Belonging and Relatedness	Youth demonstrate persistence, utilize problem-solving skills and seek help when faced with learning challenges, obstacles, and setbacks.
Purpose and Relevance	Youth demonstrate active participation and interest in science learning.
Competency and Self-Efficacy	Youth feel like they belong in the learning environment, can relate to others and to the topics they are learning within the program.
Constructive Coping and Resilience	Youth believe that learning activities and professional work in science are meaningful, important, and worthwhile.
Cognitive Engagement	Youth believe that they have the capability to succeed in learning opportunities and careers that involve science.

FIGURE 1 | Definitions of each STEM component used in the pre- and post-survey.

AN ILLUSTRATIVE EXAMPLE--STEM BEYOND SCHOOL PROGRAM

Background

The empirical example we provide for this paper is the STEM Beyond School (SBS) Program, which was designed to better connect youth in under-resourced communities to STEM learning opportunities by creating a supportive infrastructure for community-based STEM OST programs (Staus et al., 2018). Rather than creating new programs, SBS supported existing community-based STEM OST programs to provide high quality STEM experiences to youth across the state of Oregon. The 27

TABLE 1 | Items comprising survey components and corresponding Cronbach's alphas.

Component and items	Cronbach's alpha (pre/post survey)
Learner identity (6 items)	0.84/.83
1. I like learning new things.	—
2. I like to solve complex problems.	
3. I like going to my out-of-school activities that involve science.	
4. I like figuring things out.	
5. I can succeed in situations that involve understanding science.	
6. I Would like a job that uses science when I'm an adult.	
Constructive coping and resilience (4 items)	0.84/.81
1. When I have difficulty learning something, I remind myself that this is important for my future.	—
2. If I get stuck, I try something different to solve the problem.	
3. If I don't understand something in science, I ask for help.	
4. If a problem in science is really difficult, I just work harder.	
Cognitive engagement (3 items)	0.89/.81
1. I find topics related to science interesting.	—
2. I enjoy learning new things in science.	
3. I Try hard to do well in science.	
Belonging and relatedness (4 items)	0.92/.86
1. I feel like I am a part of this program.	—
2. I feel respected in this program.	
3. I feel comfortable in this program.	
4. I Feel like I can be myself in this program.	
Purpose and relevance (4 items)	0.89/.86
1. Science is important for my future.	—
2. Learning science teaches me valuable skills.	
3. Science helps people solve problems to make the world a better place.	
4. Science helps people understand the world.	
Competency and self-efficacy (3 items)	0.91/.87
1. I am good at science.	—
2. I can help others understand science.	
3. I am good at solving challenges that involve science.	

TABLE 2 | Comparison of pre- and post-survey outcome scores for six affective constructs related to STEM learner identity and motivational resilience (n = 172).

STEM outcomes	Pre-survey		Post-survey		*t*-value	*p*-value	Cohen's *d*
	Mean	SD	Mean	SD			
Learner identity	3.84	0.87	3.75	0.90	1.50	0.136	0.11
Cognitive engagement	4.10	1.00	3.94	0.97	1.99	0.047	0.16
Resilience	3.92	0.85	3.89	0.88	0.49	0.626	0.03
Belonging	4.12	1.04	4.12	0.99	0.01	0.991	0.00
Relevance	4.04	0.97	4.09	0.91	0.56	0.577	0.05
Self-efficacy	3.55	1.12	3.51	1.14	0.58	0.566	0.04

Note: Outcomes coded on a five-point scale from 1 = "Strongly disagree" to 5 = "Strongly agree."

participating programs took place predominantly off-school grounds, served youth in grades 3 through 8, and provided a minimum of five different highly relevant STEM experiences located in their communities. The community-based programs were required to provide at least 50 h of learning connected to the interests of their youth that followed the SBS 4 Core Programming Principles (student driven, students as do'ers and designers, students apply learning in new situations, relevant to students and community-based). For comparison, elementary students in Oregon receive 1.9 h per week of science instruction (Blank, 2012). SBS was therefore a targeted investment towards dramatically increasing meaningful STEM experiences for underserved youth while also advancing the capacity of program providers to design and deliver high quality STEM activities for youth that center around learning in and from the community.

SBS requires programs to intentionally engage historically underserved youth, specifically youth from communities of color and low-income communities as well as youth with disabilities and those who are English-language learners. With a grant requirement of engaging at least 70% participation amongst these groups, programs were challenged and inspired to rethink their traditional ways of reaching out, recruiting, and retaining those students.

To ensure long-term benefits for youth, SBS provided capacity building support to the community-based programs in the form of educator professional development, program design guidance, a community of practice for participating providers, support from a Regional Coordinator, and equipment. Educators working directly with youth participated in high quality, high dose (70 h for new providers and 40 h for returning providers) professional development connected directly to their specific needs. Professional development categories included essential attributes in program quality, best practices in STEM learning environments, fostering STEM Identity, and connecting to the community. Rather than providing one-size-fits-all workshops, the program assessed the needs of the educators and then leveraged expertise from across the state to address specific training or coaching needs. This approach created a community- and peer-based "just-in-time" professional learning experience that allowed educators to modify their programming in real time.

Methods and Findings

Like many of the studies discussed earlier, our evaluation of the SBS Program used a pre-post survey design to measure changes in youth outcomes over the course of the OST experience. The survey was developed in conjunction with the Portland Metro STEM Partnership's Common Measures project which was designed to address the limitation of current measurement tools and evaluation methodologies in K-12 STEM education (Saxton et al., 2014). The resulting STEM Common Measurement System includes constructs that span from student learning to teacher practice to professional development to school-level variables. For the purposes of the SBS Program evaluation, we chose six of the student learning constructs related to learner identity and motivational resilience in STEM-related activities as our outcome measures (**Figure 1**). The original Student Affective Survey Saxton, et al. (2014) was modified by revisiting its research base and examining additional research (e.g., Cole, 2012). Scales were shortened based on results from a reliability analysis of the included scales of the pre survey in year 1 of the SBS program, and in response to concerns about length and readability from program provider feedback, which led to a redesign of the post survey for the final measure (O'Connell et al., 2017). The final measure consisted of 24 items with three to six items per STEM component, which were slightly modified from the original to be suitable for OST programs rather than classroom environments (see **Table 1** for component items and alphas). In addition to these learning outcomes, the pre-survey included demographic items (e.g., gender, age) and an open-ended question to assess youth motivation for participating ("please tell us about the main reason that you are participating in this program"). The answers to this motivation question fell into three categories: 1) interest in STEM topics and activities; 2) wanted to do something fun; 3) compelled by parents or guardians.

Of the 361 youth who participated in the SBS pre-survey in year 3, 148 also completed a post-survey enabling us to examine changes in outcomes associated with SBS programming activities. Here we present the findings in two ways: a variable-centered approach examining mean changes in outcomes for the sample as a whole, and a person-centered approach in which we identify unique motivation-related subgroups of individuals and examine changes in outcomes for each subgroup. We then discuss the usefulness of the person-oriented approach and the variable-oriented approach for addressing the issue of the ceiling effect in ISL research and evaluation projects.

Variable-Centered Analysis

We conducted paired t-tests to examine overall changes in outcomes over the course of the SBS Program and found no significant changes for five of the six outcomes (**Table 2**). Although there was a significant decline in cognitive engagement, the effect size was

TABLE 3 | Comparison of changes in pre- and post-survey STEM outcomes by subgroup.

	Pre-survey		Post-survey				
STEM outcomes	**Mean**	**SD**	**Mean**	**SD**	**t-value**	***p*-value**	**Cohen's d**
Learner identity							
Interest	4.11	0.68	3.97	0.86	1.83	0.071	0.18
Fun	3.75	0.81	3.58	1.00	1.16	0.253	0.19
Compelled	3.41	0.98	3.45	0.85	0.33	0.748	0.04
Cognitive engagement							
Interest	4.41	0.69	4.17	0.82	2.80	0.006	0.32
Fun	4.05	1.07	3.68	1.19	1.65	0.108	0.33
Compelled	3.70	1.19	3.68	1.06	0.18	0.862	0.02
Resilience							
Interest	4.17	0.67	4.03	0.85	1.74	0.085	0.18
Fun	3.84	0.96	3.81	0.90	0.12	0.903	0.03
Compelled	3.56	0.97	3.66	1.02	0.52	0.609	0.10
Belonging							
Interest	4.43	0.79	4.31	0.82	1.22	0.227	0.15
Fun	4.51	0.53	3.98	1.01	2.48	0.019	0.66
Compelled	3.65	1.25	3.83	1.11	0.78	0.441	0.15
Relevance							
Interest	4.38	0.67	4.25	0.78	1.68	0.097	0.18
Fun	3.91	0.95	3.85	1.15	0.29	0.775	0.06
Compelled	3.77	1.15	3.90	0.99	0.65	0.520	0.12
Self-efficacy							
Interest	3.80	0.98	3.78	0.94	0.12	0.902	0.02
Fun	3.56	1.14	3.24	1.36	1.68	0.104	0.26
Compelled	3.16	1.24	3.16	1.21	0.00	1.000	0.00

Note: Items in index were coded on a five-point scale from 1 = "Strongly disagree" to 5 = "Strongly agree." Interest (n = 84), Fun (n = 32), Compelled (n = 32).

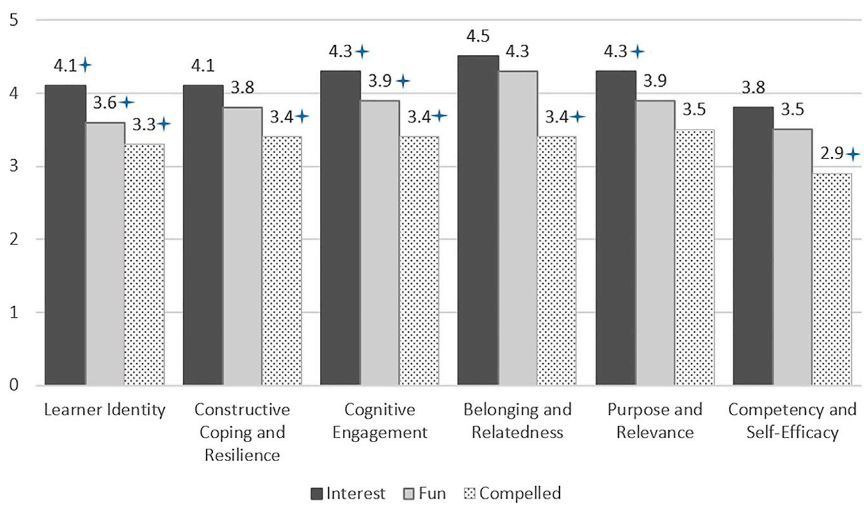

FIGURE 2 | Mean scores for all youth who participated in the pre-survey by motivation class; means with an asterisk are different at the $p < 0.05$ level. All constructs were measured on a scale of 1 (Strongly disagree) to 5 (Strongly agree). Note: n = 202 for Interest; n = 89 for Fun; n = 70 for Compelled.

small (d = 0.16). In other words, this analysis indicated that, on average, youth who participated in SBS maintained their STEM identity and motivational resilience over the course of the program but did not show the increases in outcomes that SBS providers desired. An examination of the pre-survey scores indicated that youth on average were already at the higher end of the scale, suggesting that the lack of significant changes in outcomes may be due to the ceiling effect.

Person-Centered Analysis

In order to address the ceiling effect in our data, we segmented youth into unique subgroups based on self-reported pre-survey motivation classes (See **Figure 2**): interested in STEM (Interest), wanted to have fun (Fun), or compelled by parents (Compelled). As described above, theory suggests that youth in these motivation classes may experience different learning outcomes from the same educational intervention. Youth in the Interest subgroup made up 56% of the sample (n = 202) and reported significantly greater feelings of learner identity, cognitive engagement, and relevance than youth in the other motivation classes in the pre-survey. The Fun subgroup included 25% of the sample (n = 89) and reported similar levels of resilience, belongingness, and self-efficacy as interested youth, similar relevance as Compelled youth, but significantly different learner identity and cognitive engagement than youth in the other subgroups. Finally, Compelled youth comprised 19% of the sample (n = 70) and reported significantly lower scores than youth in other subgroups on all outcome measures except relevance.

We then conducted paired t-tests for the 148 youth who completed both a pre- and post-survey. Results indicated only two significant ($p < 0.05$) changes over time: Interested youth reported a significant decrease in cognitive engagement with a moderate effect size (d = 0.32), and youth in the Fun subgroup reported a decrease in feelings of belonging with a large effect size (d = 0.66) (**Table 3**). None of the subgroups reported significant increases in any of the outcome measures at the end of the program.

DISCUSSION

The above example showed how using person-centered approaches in the evaluation of OST programs has the potential to address the ceiling effect. By segmenting the sample in a theory-driven way, we created three subgroups based on motivation to participate, two of which (i.e., Fun, Compelled) reported low enough pre-survey scores to potentially indicate increases in outcomes as a result of the OST program. In our example, neither the variable-centered nor person-centered approach revealed significant positive changes in outcomes as a result of participating in the program. However, the person-centered approach provided the opportunity to identify such changes for different subgroups of participants. For example, if an OST program led to increased outcome scores for less STEM-motivated youth, such a finding could provide important evidence to funders about the efficacy of OST programs thus promoting longevity of successful STEM-focused youth programs.

Even in the absence of significant changes in STEM outcomes, person-centered approaches provide a more nuanced view of the youth and why they participated which is valuable information that program providers can use to inform future improvements to the program. In the case of SBS, knowing that almost half of youth participated for reasons other than interest in STEM could lead to the development of more effective educational strategies that provide a range of activities designed to engage youth in each motivational category, rather than relying on one-size-fits all programming strategies. Indeed, a recent longitudinal study of youth STEM learning pathways highlighted the importance of customizing STEM resources in the larger learning ecosystem based on the differing interests and motivations of youth in the community (Shaby, et al., 2021). For example, one youth with a strong interest in computer programming eventually lost interest because the content of the OST program he attended did not keep pace with his growing interest in learning new coding languages. While it is unclear why youth outcomes remained largely unchanged after participation in SBS, it is possible that the programming was unable to adequately serve youth with a diversity of interests and motivations for participating.

It is also possible that in addition to the ceiling effect, the study may have suffered from another common measurement challenge associated with traditional pre-post designs known as response shift bias in which participants' comparison standard for measured items (e.g., competency and self-efficacy) differs between pre- and post-assessments (Howard and Dailey, 1979). In other words, program participants may overestimate their knowledge and ability at the beginning of an intervention, while post survey scores may reflect more accurate assessments based on comparisons to others in the program or simply a better understanding of the constructs themselves. Either way, a response shift may exacerbate the ceiling effect and seriously hamper the assessment of true change over time for many respondents (Oort, 2005). One potential remedy to address response shift bias is the use of retrospective pre-post (RPP) designs to simultaneously collect pre- and post-assessment data at the end of a program (Howard, Ralph, et al., 1979). This design provides a consistent frame of reference within and across respondents allowing real change results to be detected from an educational intervention. A growing body of evidence supports the use of the RPP design as a valuable tool to evaluate the impact of educational programs on a variety of outcomes (Little et al., 2020).

Ultimately, to avoid ceiling effects, assessment instruments must be designed to measure outcomes in such a way that participants with a strong affinity for STEM are not already at the high end of the scale when they begin the program. This includes choosing to measure constructs that are not theoretically limited in scale. For example, psychological constructs such as interest have a finite number of phases--once a learner has reached the highest level of individual interest, they will be unable to indicate an increase due to participation in an educational program (Hidi and Renninger, 2006). In contrast, measuring a learner's change in content knowledge may be less limited. Thus, although there is a strong call to use standard, published or previously validated measures in evaluations Noam and Shah (2013), Saxton et al. (2014), instead of ad-hoc measures adjusted to the nature of a program or the characteristics of the target audience, this may increase the prevalence of the ceiling effect in programs with high positive selection bias if measures are not designed to detect changes over time at the upper end of the distribution.

While it may not be possible to avoid measurement issues such as the ceiling effect altogether in assessments of OST STEM programs, evaluators should be aware of the methodologies and analytic approaches that could be used to address them more effectively. In particular, person-centered approaches that allow the segmentation of participants into motivation-related or other theory-driven subgroups, perhaps in conjunction with retrospective pre-post-survey designs, should be considered at the outset of program evaluations whenever possible.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The data are shared with partner organizations whose permission we would need to share publicly. Requests to access these datasets should be directed to stausn@oregonstate.edu.

AUTHOR CONTRIBUTIONS

NS, KO, and MS contributed to conception and design of the paper. NS organized the information and wrote the first draft of the manuscript. NS and KO wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Is Science for Everyone? Exploring Intersectional Inequalities in Connecting With Science

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Several studies have investigated the way learners connect with science, re-emphasising persisting inequalities in science learning. This article combines the concept of intersectionality with the theoretical lens of science learning ecologies to focus on inequalities in connecting with science: Which factors influence the formation of a positive science attitude of young learners and how does the social background of young learners influence their opportunities of connecting with science, focusing on the intersections of class and gender? Based on a quantitative survey among 1,486 visitors of non-formal science education offers aged between 8 and 21, we analyze important factors for the development of a positive science attitude and investigate structural inequalities. The intersectional perspective was implemented in the sampling, survey design as well as its analysis. Using composite indicators of age and gender as well as gender and educational capital, we avoid a homogenisation of broadly defined groups. The results highlight that the development of a highly positive science attitude–as identified in a stepwise logistic regression model–is linked to supportive social environments, intrinsic motivation, science learning in school as well as regular engagement in arts-based learning, and self-directed science learning. The learning ecology perspective illustrates the influence of school on science attitudes in general. From an intersectional perspective, however, our findings demonstrate that the persistence of an androcentric and classist concept of science is not compatible with every learning ecology; male learners from educationally affluent backgrounds are most likely to enjoy science learning and see how science relates to their everyday realities. In turn, however, not only female learners with lower educational capital but also male learners with lower educational capital might find it more difficult to connect with science. The intersectional approach unveiled the multiple ways educational capital and gender shape individual learning ecologies. More equitable science learning spaces and offers have to adapt to a diversity of needs and preferences in order to make science activities enjoyable for all.

Keywords: science learning, intersectionality, learning ecology, structural inequalities, gender, educational capital, science attitudes

INTRODUCTION

Popularly, science is connected to cleverness, intelligence, and academic success (Archer et al., 2013a; Archer et al., 2014). Access and inclusion in science-affine communities are based on the socialisation of given norms and practices as well as on the development of self-identities compatible with these communities (Carlone and Johnson 2007). In this sense, science is not for everyone, but for those complying with the "dominant cultural conventions of thought and action" (Grenfell 2004, 50), producing inequalities between young learners and their connection to science.

Several studies have investigated the way learners develop interests in science, learn about science, develop science attitudes or (aspire to) pursue science related careers putting an emphasis on single demographic features such as gender or social class (e.g., Bricheno 2001; Papanastasiou and Papanastasiou 2004; Barron 2006; Gorard and See 2009; Milgram 2011; Burns et al., 2016). In contrast to these studies, we focus on the intersection of class and gender and investigate 1) which factors influence the formation of positive science attitudes of young learners. 2) We explore how the social backgrounds of young learners potentially influences their opportunities of connecting with science (Archer et al., 2013a; Archer et al., 2014). Building on the results of a large-scale survey on science learning for youths aged between 8 and 21 in 17 countries across Europe and Israel/Palestine, we aim at identifying potential boundaries for young learners in connecting with science. This knowledge may support the development of more inclusive concepts of science learning and hence provide ways to tackle inequalities in science learning. The chosen theoretical lenses guiding this investigation are twofold:

Firstly, the perspective of learning ecologies is applied, highlighting the influence of young learners' personal backgrounds on their opportunities to connect with science. The concept of learning ecologies explains a child's development in relation to their environment. Based on Barron (2006), this article conceives learning ecologies as "the set of contexts found in physical or virtual spaces that provide opportunities for learning [. . .]. Each context consists of a unique configuration of activities, material resources, relationships, and the interactions that emerge from them"(Barron 2006, 195). In the context of science learning, this perspective suggests that the specific relation between individuals and the environment shapes the way information is perceived and acquired. Whilst the conceptions of science learning ecologies have been criticised for failing to properly address "affective and extrarational influences" (Johnston et al., 2006, 909), our approach entails that (science) learning is understood as a cognitive, behavioural and affective process (Carlone and Johnson 2007; Falk et al., 2016) that is socio-culturally embedded. Prior knowledge of science topics that learners are interested in and their interactions with others (Anderson et al., 2015) shape youths' educational experiences in and across formal and non-formal settings (Bevan 2016).

Secondly, an intersectional approach is applied, aiming at studying science attitudes and the engagement in various science activities at different intersections of identities, social positions or institutional practices in the educational context (Bowleg 2008; Bauer 2014). Originally developed for capturing the living realities of black women (Crenshaw 1989), the concept of intersectionality emphasises the interaction of gender and race as markers of structural inequalities on and across each other. Henceforth, the approach has been opened up to further categories of social differentiation and discrimination such as migration histories, class, dis_ability or sexual orientation. In our context, this research lens suggests that taking account of additional intersections can establish further layers of dis-/identifying with science (Brickhouse et al., 2000; Bell et al., 2009; Hazari et al., 2013). Thereby, intersectionality complements the concept of "science identities," which is gaining attention in science education literature (Carlone and Johnson 2007). Despite the awareness that intersectionality itself offers a useful and valuable conceptual framework of studying science learning, until now, it has been hardly used in respective research (see e.g., Artiles 2013; Traxler et al., 2016; Avraamidou 2020; Cochran et al., 2020), and is difficult to operationalise from a quantitative perspective (see e.g., Bauer 2014; Rouhani 2014). Nevertheless, in this study intersectionality was considered at the level of survey design, sampling strategy as well as analysis.

The intersectional learning ecology approach pursuit in this paper demonstrates the relevance of intersectional analyses to obtain a fine-grained understanding of factors affecting (in)equity in science learning. Inspired by the work of Louise Archer and colleagues for the United Kingdom context (2012, 2013, and 2014) and studies following the concept of cultural reproduction (Bourdieu 2001), this paper specifically focuses on the intersections of gender and the socio-educational background that structure learners' self-identities, their social environments and cultures, as well as their chances to connect with science.

As the approach of learning ecologies puts forward, concepts of science and those who partake in it do not exist in a vacuum. Families, attitudes of peers and the formal educational system are regarded as important contexts affecting the formation of science attitudes (Bricheno 2001).

The family is the first and most important place of primary socialisation; where knowledge, skills, norms, values, and traditions are learned (Anastasiu 2011). The family's educational, financial, and occupational background and hence its social class and socio-economic status have been identified as stratifying factors of participation and accomplishment in the formal education system (Bell et al., 2009; Gorard and See 2009; Archer et al., 2012). Additionally, formal educational systems provide for the reproduction of the social status of those complying best with its norms and educational concepts (Goldthorpe 2007).

Consistent with this, researchers have found that the formal education system does not create spaces where multiple perspectives of knowing and showing science can emerge and hence, does not foster diversity (Barton and Osborne 2001). Narrowly defined and acknowledged science identities in turn do not appeal to a broad range of students coming from diverse living situations, entering the formal education system equipped with their own set of knowledge, cognitive skills and beliefs of how the world works (Bell et al., 2009; Jordan 2010). This is why the formal educational system acts as a gatekeeper potentially restricting the education pathways of learners not sharing the same habitus (Bourdieu 2001).

Scientists are perceived as persons working with their minds. Accordingly, this popular image affects how children connect with science depending on their social backgrounds. Following the theory of cultural reproduction (Bourdieu 2001), Archer and colleagues introduce the concept of the "family habitus" (Archer et al., 2012, 886) to refer to the science capital of a family. This capital not only entails specific "resources, practices, values, cultural discourses" (Archer et al., 2012, 886), but also includes the family identity in which one is born into. As such, well-off middle-class families tend to condense science-specific cultural and social capital with a sense of a science-related image providing a supportive context for their children's science interests (Archer et al., 2012). Working class families with a lower socio-economic status and less cultural capital in turn tend not to perceive science as part of their being. Instead, science is not part of their daily family practices and hence something rather "unthinkable" for their children (Archer et al., 2012). Carina Altreiter (2017) supports this argument by explaining that habitual rooting of career aspirations of the Austrian working-class is related to the idea of using one's own hands and body instead of working predominantly with the mind.

Children from economically poorer families are not necessarily found to be less interested in science. However, they are found to be less likely to choose science as a subject, based on its perceived difficulty, its image within their social class and the influence of their families (Gorard and See 2009).

The popular image of natural scientists, as intelligent persons predominantly working in a lab, is also framed by the gendered division of labor. Working with one's mind is not only predominantly attributed to higher educated people but has also historically been framed as masculine (Hausen 1976). In contrast to the feminine-constructed caring body and emotionality, the human brain and rationality are constructed as part of a male gender identity (Hausen 1976). Stemming from the 19th century, attributing science and brain work to men shapes the dominant image of science and scientists until today; an image re-creatable by children as young as the age of six (Carlone and Johnson 2007; Archer et al., 2013a). These relational gender stereotypes and conceptions of femininity and masculinity can make science seem "incompatible with girls' performances of popular/desirable hetero-femininity" (Archer et al., 2013a, 181). On this basis, gender disparity in science was found to be reversed with students not identifying as heterosexual (Hughes 2018).

While at a young age, science interests do not statistically significantly vary with gender, binary (i.e., male and female only, as other groups have not been researched) gender differences manifest themselves as children grow older (Archer et al., 2012; DeWitt et al., 2013). Gender stereotypes have also been found to be reproduced by parents (Bell et al., 2009). In older studies, mothers overestimated the mathematical skills of their sons and underestimated those of their daughters. Mothers also tended to talk about science more with boys than girls (Frome and Eccles 1998). In more recent studies, fathers' increasing gender stereotypes were observed to be negatively related to girls' interests in mathematics, while positively related to boys' enthusiasm in the subject (Jacobs et al., 2005). Further, fathers tended to employ more cognitively demanding speech with boys than girls (Tenenbaum and Leaper 2003). In short, parents and other adults support and encourage boys and girls differently (Falk et al., 2016). Given the influences of stereotyping and the social influences of peers, teachers and parents, some researchers still find female learners reporting less positive science attitudes than male learners (Bricheno 2001). Miller and Budd (1999) suggest that stereotyped views of science tend to decline for girls, while boys are more likely to hold stereotyped views of science (Bricheno 2001), stipulating more positive science attitudes in general.

In addition, (Archer et al., 2013a) underline that ideas of (hetero-) masculinity and (hetero-) femininity differ by social class. Boys from working-class contexts are less likely to see how science relates to their lives than boys from middle and upper classes (Archer et al., 2014). The class-gender intersection, however, exacerbates more strongly with regards to girls from working-class backgrounds, resulting in their exclusion from both corresponding to the androcentric ideal of science students and having science-related future aspirations (Archer et al., 2013a).

The paper at hand builds on these findings and is structured as follows: First, we start with the operationalisation of the main theoretical concepts used in this paper: positive science attitudes, non-identification with science and engagement in (science) learning. In this context, we also introduce the two datasets analyzed. Second, we present the empirical results, where we start with summarising the results of a regression analysis of the main parameters affecting the development of a positive science attitude. We then continue to explore group-based intersectional differences in the way young learners connect with science, focusing on gender and educational capital. In the conclusion, we discuss how our findings interrelate and potentially contribute to a more inclusive concept of science learning and highlight the benefits of our combined methodological approach.

MATERIALS AND METHODS

To investigate differences in the way young learners connect with science on the basis of their learning ecologies and self-perception, we built on the work by John Falk et al., (2016) and developed a self-administered quantitative survey[1]. Dimensions addressed in the survey comprise the everyday engagement with science, the social environment, attitudes towards science in general and attitudes towards science lessons at school. In addition, to implement intersectional analyses later on, socio-demographic information about the learners' age, gender identities (operationalised as an open question "What gender do you identify with" and coded

[1]The survey can be found in the **Supplementary Material** to this article.

afterwards), migration histories (operationalised as countries born in vs. country living in and languages spoken at home) and self-perceived dis_abilities was collected. While race/ ethnicity exceeds the collected dimension of migration histories and was considered an important marker of inequality for intersectional research, its operationalisation in the European context turned out to be beyond the abilities of the survey. The multinational context of the project would have required a country-specific operationalisation of ethnic self-identification allowing for a context-specific interpretation of the collected results (Hoffmeyer-Zlotnik and Warner 2010). In addition, being a sensitive category, several EU Member States have legal frameworks strongly regulating the collection of data on ethnicity, with e.g., France prohibiting the collection of data on ethnic origin (Farkas 2017). As a result, race/ethnicity was not surveyed and is therefore excluded from this study. Questions about the highest level of education and current field of employment of the parent(s) were included in the consent sheet, completed by the parents (in case of minors) or young learners themselves (in case of older learners).

The research design was aligned with the project consortium of SySTEM 2020, an EU-funded research project focussing on non-formal science education, coordinated by Science Gallery Dublin and represented by research institutions and 19 museums, science centers, and maker spaces located in Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Greece, Ireland, Israel/Palestine, Italy, Netherlands, Portugal, Serbia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

The targeted population was represented by learners aged between 8 and 21 who engaged in non-formal science educational events of the partner institutions. The specifically set-up convenience sampling strategy was embedded in an intersectional framework where the project partner institutions were asked to reach out to all their user groups putting an emphasis on engaging different age groups, gender identities and learners with migration histories. The project partners reached out to their visitor base as well as associations working with non-dominant youths and schools to engage survey respondents. To investigate possible changes of the learning ecologies over time (Barron 2006), the survey was set up in two waves, engaging the same participants twice within the timeframe of a year. The source questionnaire designed in English was piloted using cognitive probing interviews (see for example Prüfer and Rexroth 2005; Miller et al., 2014). Each of the 14 subsequently translated questionnaires was tested again using cognitive probing interviews with young learners to ensure the quality of the questionnaire and the resulting data.

In the first wave, learners were invited to participate in a workshop organised by each of the involved project partners where they completed the survey on paper. These workshops, which were all organised differently and focussed on different science-related topics, took place between February and April 2019. The same participants were reached out to in wave 2, between February and June 2020. In addition, several new respondents, who fit the sampling profile, were involved in the second wave, to reach a comparatively large sample size as in wave 1. During the second wave, the survey could also be completed online, an option that was particularly useful based on the specific COVID-19 induced measures of physical distancing during that time.

In total 1,468 individuals were engaged in the survey; 736 of them completed the survey twice and hence their responses could be investigated with regards to changes between measurement times. The data of wave 1 and wave 2 was matched by a pseudonymised ID, ensuring data protection rights. All data collected was analyzed descriptively. The sample surveyed twice (abbreviated "twice") and a pooled sample of 732 learners, who answered the survey only once, either in wave 1 or wave 2, (abbreviated "once"), were also analyzed exploratorily, constructing a regression model with a focus on the impact of age, gender, the families' educational capital, and their various intersections on the formation of science attitudes of young learners.

Most learners identified themselves within the gender binary as male or female or boys and girls respectively. Only 10 learners identifying beyond the gender binary participated in the survey, eight of them make part of the sample surveyed twice (1% of those answering twice). Based on this small sample size, their answers unfortunately needed to be excluded for gender-based analyses. From a binary perspective, both samples were about gender balanced.

In general, learners from low, medium, and highly educated households were part of the surveyed population. To explore the impact of different educational backgrounds of parents and their social and occupational status on their children's possibilities to connect with science, an index measuring "educational capital" of the learners' families was created. Following Bourdieu, educational capital can be defined as "incorporated cultural capital" (Bourdieu 2007, 95), an educational status that has been achieved by young learners' parents and has become part of the self-identity of young learners, shaping their values and attitudes. In our study, educational capital was hence measured as index using the highest level of education, the current profession of the learners' parents (collected according to ISCO-08 major groups) as well as the number of physical reading materials available in the household (DeWitt et al., 2013) (Cronbach's $\alpha = 0.57$[2]). In case that both parents' educational and professional status was collected, only the data of the higher-ranking parent was included in the index (International Labor Organisation 2008). The resulting index ranged from 2 (indicating the lowest score) to 10 (indicating the highest score). The scale was then summarised into three categories: low educational capital, ranging from 2 to 4.5; medium, ranging from 4.6 to 7.5, and high educational capital, ranging from 7.6 to 10.

Apart from physical reading materials available at home, resources for learning were measured by counting the number of electronic devices available, as well as music instruments. Most of the surveyed learners (>90%, $1,398 < n < 1,410$) have devices such as computers, smart phones and TVs in their homes that might enable science learning. 70% of all individuals, who

[2]Cronbach-α measures the internal reliability among items (see e.g., Field 2012). Values above 0.7 are considered a good fit, values below 0.5 as inacceptable.

answered this question (n = 1,418), indicated having musical instruments at home. Learners from higher educated households were more likely to have musical instruments at home (twice: χ^2 (6) = 87, p < 0.001, once: χ^2 (6) = 52, p < 0.001).

Since the sampling strategy targeted youth visiting and using non-formal science institutions, learners from households with higher educational capital are overrepresented in both samples. Comparing both samples, learners from households with low educational capital, learners with histories of migration and learners indicating facing serious difficulties with hearing, speaking or moving were more strongly represented in the sample surveyed once. More of these learners dropped out after wave 1 (n = 589), which included 1,322 respondents in total. In contrast, newly included members of wave 2 (n = 146), rolled out as an online survey among the institutions' contacts fitting the description of the target group of the study, largely came from more privileged groups. Young learners who participated twice in the survey tended to live more often in cities, be slightly older and therefore tend to have a higher level of education themselves.

Learners who participated twice in the survey are also more likely to express a particularly positive science attitude (70% did so vs. 24% of one-time-respondents). The process of positive self-selection caused by the approximative longitudinal design impacted the representativeness of the groups, which is why the sample of wave 1 or wave 2 only respondents is more representative of the young learners reached by the institutions offering non-formal science learning programmes in general.

Operationalisation of the Ways to Connect With Science

To measure science attitudes, engagement, and aspiration across European contexts we adapted survey questions suggested by the Synergies project in the US (Falk et al., 2016) and the ASPIRES project in the United Kingdom (Archer et al., 2013b) as both operationalised a learning ecologies perspective: To investigate the underlying, latent and multidimensional elements of science learning in various contexts and attitudes towards science-learning, an exploratory principal component analysis (PCA) was conducted with data collected from both samples at the time of wave 1 (n = 1,322). This method identifies the minimum numbers of factors consistently, summarising the interrelated items into a single, yet multidimensional variable (Field et al., 2012).

Exploring the underlying factors that explain young learners' ways to connect with science, 18 items were included in the PCA.[3] From this, five factors were identified: 1) a positive science attitude, 2) non-identification with science, 3) learners' attitudes towards science lessons in school, 4) parental science relevance, and 5) friends' science attitudes. Each factor was then modeled as a mean-based index summarising the related variables, values ranging from 1 to 5, with 1 implying the strongest possible opposition towards the measured concept and 5 the strongest agreement.

The factor-based index called "positive science attitude" (Cronbach's α = 0.86, indicating high scale reliability) summarises the enjoyment and fascination with science, an interest in science and an idea of how science relates to one's own life, including potential career paths. Science attitudes in general capture the emotional orientation of an individual to respond favourably to science (Papanastasiou and Papanastasiou 2004). The results of the factor analysis imply that a positive concept of science relates to the individual learners' lives and hence touches on aspects which are often considered as part of the learner's self-identity (e.g., Carlone and Johnson 2007).

The PCA also pinpoints the factor-based index "non-identification with science" (Cronbach's α = 0.59), which is more explicitly related to the concept of science identity (Falk et al., 2016) summarising negative attitudes such as the feeling that science does not relate to oneself, to one's way of learning and thinking and feeling that others relate more easily to science.

The two separate factors identified in our PCA explain 65% of overall variations and indicate the need to empirically differentiate between "positive science attitudes" and the "non-identification with science," as both relate to different aspects of the multidimensional concept of science identities.

The other three factors (of five factors identified by the PCA) are considered as structuring young learners' science ecologies, and hence as potentially explaining differences in the way young learners connect with science and build their own science identities.

The PCA identified index "attitude towards science lessons in school" (Cronbach's α = 0.85) mirrors the learner's excitement with science classes in the formal education system. The factor "parental science relevance" (Cronbach's α = 0.79) captures parental influence on individual science attitudes, describes parental science interest and captures parent-child discussions about science. Lastly, the factor "friends' science attitudes" (Cronbach's α = 0.84) summarises the perceived positive science attitudes of the learners' close friends.

A second obliquely rotated PCA was applied exploring the different ways young learners engage with science. As informal learning processes are ubiquitous, the activities probed here do not only include activities such as watching a video about science, but also learning to play a musical instrument, or gardening and were selected on the basis of the Synergies project (Falk et al., 2016). Among all activities three factors[4] were identified, two of

[3]The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.89 and Bartlett's test of sphericity was significant (p < 0.001). Indicating that correlations between items were sufficiently large for performing a PCA. Only factors with eigenvalues ≥1 were considered (Guttman 1954; Kaiser 1960). Examination of Kaiser's criteria and the scree-plot yielded empirical justification for retaining four factors with eigenvalues exceeding 1 which accounted for 100% of the total variance.

[4]The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.67 and Bartlett's test of sphericity was significant (p < 0.001). Indicating that correlations between items were sufficiently large to perform a PCA. Only factors with eigenvalues ≥1 were considered (Guttman 1954; Kaiser 1960). Examination of Kaiser's criteria and the scree-plot yielded empirical justification for retaining three factors with eigenvalues exceeding 1 which accounted for 100% of the total variance.

them are discussed hereafter: 1) The factor "self-directed science-learning" (Cronbach's α = 0.63) summarises the regular engagement in building things, taking them apart or repairing them; doing science experiments at home; watching science-related videos; visiting a website about science, maths or technology outside of school. On this basis, a mean-based index (range 0–4) summarising the frequency of engagement in these four activities was constructed. 2) The factor "arts-based learning" (Cronbach's α = 0.65) relates to regular engagement in arts activities, which were found positively relating to science achievement (e.g., Črnčec et al., 2006; Hille and Schupp 2015). This factor in our study includes the following variables: learning a musical instrument; pursuing dance; partaking in drama or acting classes; pursuing correlating after-school programmes. This factor was also remodeled as a mean-based index (range 0–4).

RESULTS

To explore the ways young learners connect with science, a stepwise logistic regression model was created and run with the two different samples ("twice" and "once"). The regression model provides insights on the main factors supporting the development of positive science attitudes (dependent variable) showing the relationship between each of the independent variables included in the model with this variable.

Answering the question how different groups of young learners connect with science the second part of the results section uses indicators to investigate significant (Bonferroni-corrected) group-based differences by age, gender and educational background of the family and the combined effect of age and gender (four groups, male and female below and above age 12), as well as gender and educational capital (six groups, low–medium–high per gender). This approach enabled to consider the intersections of gender and the learners' social backgrounds and their manifestation in different age groups. Doing so, we followed the observations by Archer et al. (2012) as well as Miller and Budd (1999) that gender stereotypes exacerbate with age and differ according to the educational background and the socio-economic status of a family.[5]

Parameters That Support the Development of a Positive Science Attitude

Which dimensions of young learners' learning ecologies influence the formation of positive science attitudes? In the following section the results of a stepwise logistic regression model are presented. To measure positive science attitudes the PCA-introduced mean-based index was used. In line with the approach of Hayes and Tariq (2000), we investigated the development of a positive science attitude, by recoding the science attitude mean-based index as a binary dependent variable with 0 indicating a negative or neutral science attitude (1–3 on the scale), and 1 indicating a positive science attitude (scoring 4 or 5 on the original index).

The model gives information on the probability of a positive science attitude developing, given the value of all included independent variables (Field et al., 2012). The regression model's assumptions were tested investigating the linear relationship between predictors and the logit of the outcome variable, testing the independence of errors using the Durbin Watson Test and investigating levels of multicollinearity using variance inflation factors.

Parameters potentially influencing positive science attitudes included in the regression model were sociodemographic variables (such as age, gender, and educational capital), variables characterising the social context of learners (such as parental science relevance and friends' science attitudes), learners' engagement in (science) learning activities outside the classroom and their perception of science in school. A detailed list of all variables included in the final model can be found in **Table 1**.

The findings of earlier studies (e.g., Archer et al., 2013b; Falk et al., 2016) as well as our intersectional lens determined the order of variable inclusion with socio-demographic variables being included first (Bauer 2014). Model fits were judged using Cox and Snell's R^2 (R^2_{CS}) as approximated indicator for the share of explained variance as well as the Akaike Information Criterion (AIC), as goodness of fit measure. The model was tested with the two different samples, the sample surveyed twice, and the sample surveyed once. Only variables significantly improving the explanatory value were kept in the model, others were sequentially removed. A full list of all variables originally tested can be found in the **Supplementary Material**. For reasons of comparability, the final mode includes the same variables for both samples, except for the parameter of change in value of science attitudes between wave 1 and wave 2 (called "time-effect"), which could only be measured among the sample surveyed twice.

For the group surveyed twice, the logistic regression model comprised 14 independent variables that explained more than a third (R^2_{CS} = 0.39) of the variations of a positive science attitude (n = 614). Based on the overrepresentation of respondents from one participating organisation in the sample surveyed once and their significant influence on the model, the second model was weighted. The explanatory value of this model was R^2_{CS} = 0.29, with 13 dependent variables (n = 622). Although the same variables were tested with both samples, except for the "time-effect," the applied independent variables tended to capture the variance of positive science attitudes of the sample surveyed twice better.

Odds ratios (OR) reported hereafter, signify the change of odds for the outcome variable (positive science attitude) resulting from a unit change in the predicting variable, with ORs exceeding 1 implying a positive change, ORs below 1 a negative change (Field et al., 2012). Since ORs are difficult to compare both within and across models, average marginal effects (AME), interpreted as the average percentage change in likelihood, were used as additional measure of the effect of the

[5]The results of all group-based comparisons can be found in the **Supplementary Material** to this article.

TABLE 1 | Regression model.

Variables included	Sample	Coefficient b (std error), *p*-value	Lower AME	AME	Upper AME	Lower OR	OR	Upper OR
Constant: Positive science attitude (0 = negative/neutral; 1 = positive)	Twice	**1.754** (0.32) $p < 0.001$	–	–	–	–	–	–
	Once	**–0.403** (0.34) $p > 0.1$	–	–	–	–	–	–
Educational capital (numeric)	Twice	**–0.021** (0.07) $p > 0.1$	–0.02	**0.00**	0.01	0.85	**0.98**	1.13
	Once	**0.112** (0.06) $p < 0.1$	–0.00	**0.02**	0.03	0.99	**1.12**	1.27
Gender (0 = female, 1 = male)	Twice	**–0.318** (0.28) $p > 0.1$	–0.09	**–0.03**	0.02	0.42	**0.73**	1.25
	Once	**0.041** (0.26) $p > 0.1$	–0.06	**0.01**	0.08	0.62	**1.04**	1.75
Enjoying science in school (numeric)	Twice	**1.004** (0.13) $p < 0.001$	0.08	**0.10**	0.13	2.10	**2.71**	3.55
	Once	**0.981** (0.13) $p < 0.001$	0.11	**0.13**	0.16	2.09	**2.67**	3.46
Self-perceived school performance (numeric)	Twice	**0.332** (0.15) $p < 0.05$	–0.07	**0.03**	0.04	0.48	**0.86**	1.51
	Once	**0.310** (0.13) $p < 0.05$	0.01	**0.04**	0.08	1.06	**1.36**	1.77
Schools involved in data collection (0 = no schools, 1 = schools)	Twice	**0.332** (0.15) $p < 0.05$	0.00	**0.03**	0.06	1.01	**1.36**	1.83
	Once	**1.035** (0.34) $p < 0.01$	0.05	**0.14**	0.22	1.45	**2.81**	5.51
Friends' science attitudes (numeric)	Twice	**0.337** (0.12) $p < 0.01$	0.01	**0.04**	0.06	1.11	**1.40**	1.77
	Once	**0.319** (0.13) $p < 0.05$	0.01	**0.04**	0.08	1.07	**1.38**	1.79
14–17-year-olds (0 = other age group, 1 = 14–17)	Twice	**0.676** (0.29) $p < 0.05$	0.01	**0.07**	0.13	1.12	**1.97**	3.52
	Once	**0.920** (0.29) $p < 0.01$	0.05	**0.12**	0.20	1.44	**2.51**	4.47
8–10-year-old**s** (0 = other age group, 1 = 8–10)	Twice	**–1.124** (0.43) $p < 0.01$	–0.21	**–0.13**	–0.04	0.13	**0.29**	0.68
	Once	**0.773** (0.47) $p < 0.1$	–0.02	**0.04**	0.23	0.89	**2.17**	5.59
Change between w1 and w2 (numeric)	Twice	**1.141** (0.19) $p < 0.001$	0.08	**0.12**	0.15	2.17	**3.13**	4.66
Parental science relevance (numeric)	Twice	**0.561** (0.13) $p < 0.001$	0.03	**0.06**	0.08	1.37	**1.75**	2.26
	Once	**0.181** (0.12) $p > 0.1$	–0.01	**0.02**	0.06	0.95	**1.20**	1.52
Self-motivation (numeric)	Twice	**0.628** (0.60) $p > 0.1$	–0.06	**0.07**	0.19	0.57	**1.87**	6.15
	Once	**2.344** (0.65) $p < 0.001$	0.15	**0.32**	0.48	2.97	**10.43**	38.48
Supportive siblings (numeric)	Twice	**–2.802** (0.99) $p < 0.01$	–0.49	**–0.29**	–0.09	0.01	**0.06**	0.43
	Once	**–1.955** (1.01) $p < 0.1$	–0.53	**–0.26**	0.00	0.02	**0.14**	1.02
Engagement in arts-based learning (numeric)	Twice	**0.125** (0.13) $p > 0.1$	–0.01	**0.01**	0.04	0.87	**1.13**	1.48
	Once	**0.299** (0.14) $p < 0.05$	0.00	**0.04**	0.08	1.03	**1.35**	1.77
Engagement in self-directed science learning (numeric)	Twice	**0.425** (0.17) $p < 0.05$	0.01	**0.04**	0.08	1.10	**1.53**	2.13
	Once	**0.316** (0.15) $p < 0.05$	0.00	**0.04**	0.08	1.02	**1.37**	1.56

Model fits were judged using Cox and Snell's R^2 (R^2_{CS}) in connection with the Akaike Information Criterion and the likelihood-ratio test for nested models. $R^2_{CStwice} = 0.39$, $R^2_{CSonce} = 0.28$. Bold value 1 (column 3) corresponds to the value of coffecients, as the column lable says, bold value 2 (AME) to the average marginal effect (AME in short), bold value 3 (OR) to the odds ratio.

independent variables on the variance of positive science attitudes (Wolf and Best 2010).

Interestingly, neither educational capital, nor gender significantly impacted the likelihood of developing a positive science attitude in both samples. Yet, for reference and for understanding their relation to other variables included, both variables were retained in the final model as discussed hereafter. Possibly, despite their hierarchical inclusion, their effects are mediated by other variables included in the model. Other tested socio-demographic variables such as migration histories, dis_abilities and fluency in multiple languages equally yielded no significant effects and were in turn excluded from the final model as listed in **Table 1**.

Only one variable turned out to influence positive science attitudes highly significantly among both samples; namely the enjoyment of science lessons in school (twice: $b = 1.00$ $p < 0.001$, once: $b = 0.98$, $p < 0.001$). Enjoying science classes more by one unit increases the likelihood of having a positive science attitude by 10% (AME_{twice}) to 13% (AME_{once}). The connection between the enjoyment of science lessons at school and the general science attitudes is reaffirmed by the impact of the learners' own perception of their performance at school on the probability to develop a positive science attitude in the sample surveyed once. A better impression of a learner's own performance at school supports the development of a positive science attitude in the sample surveyed once ($b = 0.31$, $p < 0.05$, AME = 0.04, OR = 1.36), whereas the impact of the same variable yields ambiguous results in the sample surveyed twice ($b = 0.13$, $p < 0.05$, AME = 0.03, OR = 0.86). Information from the involved project partners on the sampling strategy implemented further shows significant effects of school involvement when engaging survey/workshop participants. In case the non-formal institutions involved in the project cooperated with schools when recruiting survey participants (which was the case for 75% of engaged participants in total), the probability of the respondents enjoying science and ability to see how it relates to their world, rose by 3% (AME) in the group of respondents answering the survey twice and by 14% in the sample surveyed once. This might hint at a preselection of schools, who have built strong ties with non-formal science institutions and thereby, potentially, stipulated science interests of their students.

In addition, the model for both samples was improved once two specific age-groups, modeled according to age-based response tendencies of the dependent variable, were included. The youngest respondents (8–10 years) of the sample surveyed twice, were found less likely to exhibit a positive science attitude (b = -1.24, $p < 0.01$, AME = −0.13, OR = 0.29), possibly hinting at ongoing processes of attitude development. In turn, young adults (14–17 years) of both samples were more likely to have a positive science attitude (twice: b = 0.68, $p < 0.05$, AME = 0.06, OR = 1.97, once: b = 0.92, $p < 0.01$, AME = 0.12, OR = 2.51). This outcome potentially confirms results of former studies demonstrating that attitudes towards science become rather stable at age 14 and those learners might have positively self-selected (Archer et al., 2013b). The oldest age group (18–21 years), however, does not mirror this trend and –based on its insignificance (possibly group size related) –is not included in the final model (**Table 1**).

Involving the engagement in specific forms of (science) learning significantly improves the model for both samples. Concerning respondents only surveyed once, the regular engagement in arts-based learning, measured by the PCA-based index introduced earlier, influences the probability of also developing a positive science attitude (b = 0.30, $p < 0.05$, AME = 0.04, OR = 1.35). The sample surveyed twice does not indicate clearly positive effects of arts-based learning. Instead, this sample shows a significant impact of regular engagement in self-directed science learning (b = 0.43, $p < 0.05$, AME = 0.04, OR = 1.53), which yields comparable effects but lacks significance among the respondents surveyed once (b = 0.32, $p < 0.1$, AME = 0.04, OR = 1.37).

Having friends, with positive science attitudes makes it more likely to develop a positive science attitude (twice: b = 0.364, $p < 0.01$, AME = 0.04, OR = 1.40; once: b = 0.31, $p < 0.05$, AME = 0.04, OR = 1.38). Interestingly, the influence of parental science relevance on the science attitudes of learners is only identified as a parameter significantly impacting science attitudes of two-times respondents. While no significant impact of parental science relevance is evident in the sample surveyed once (b = 0.18, $p > 0.1$, AME = 0.02, OR = 1.20), parents who are interested in science and talk to their children about it significantly impact the positive science attitude in the sample surveyed twice (b = 0.56, $p < 0.001$, AME = 0.06, OR = 1.75). In turn, siblings supporting science learning have a negative influence on the learners' probability to develop a positive science attitude. This effect is highly significant in the sample surveyed twice (b = −2.80, $p < 0.01$, AME = −0.29, OR = 0.06), but the same insignificant tendency, is visible in the sample surveyed once (b = −1.9555, p = 0.051, AME = −0.262, OR = 0.1421). 37% of the learners in the sample surveyed twice (n = 736) and 40% of the group of respondents surveyed once (n = 732) perceived their siblings as encouraging. Possibly, the siblings' encouragement might be prompted by specific living conditions not included in the model, which also negatively correlate with the chance of developing a positive science attitude.

Among one-time respondents it is not so much the learners' socio-cultural environments, but their own intrinsic motivation that highly significantly impacts their likelihood to develop positive science attitudes (b = 2.34, $p < 0.001$, AME = 0.32, OR = 10.43). Comparing the two waves of the sample surveyed twice, an effect of time on science attitudes is also evident. While only a small fraction (9%, n_{twice} = 728) of the learners experienced changes exceeding a one-point difference on the index between wave 1 and wave 2, a positive change between the two waves significantly improves the probability of a positive science attitude (b = 1.15, $p < 0.001$, AME = 0.12, OR = 3.15).

Summarising the results of the regression model, we see that the learners' self-motivation to regularly engage in science related activities (including arts-based activities potentially fostering informal science learning), science interests at school and the self-perception of young learners' performance at school explain the likelihood of having a positive science attitude best. Yet, who are the young learners with a positive science attitude and a low probability to non-identify with science? What differences do learners' identities related to gender, age and educational capital make? To answer these questions the effects of age, gender and educational capital of young learners were explored.

EXPLORING DIFFERENCES AFFECTED BY LEARNERS' SELF-IDENTITIES CONNECTED TO GENDER, AGE AND SOCIO-ECONOMIC STATUS

Group differences were tested against the indices stemming from both earlier introduced PCAs identifying dimensions of young learners' science attitudes and engagement with science. The effects of age, gender, and educational capital on the way young learners of different socio-economic status connect with science are reported according to the following dimensions: 1) science attitudes and non-identification with science 2) engagement in learning, and 3) importance of science for the social environment.[6]

Science Attitudes and Non-identification With Science

In total, 70% of the sample surveyed twice (n_{twice} = 728), but merely a quarter (24% n_{once} = 730) of the sample surveyed once indicated a positive science attitude, hence enjoy science learning and see how science relates to their everyday lives. In contrast to the regression analysis, the comparison of means shows significant impacts of the educational capital of the learner's probability to exhibit a positive science attitude. Learners from highly educated backgrounds are significantly more likely to exhibit a positive science attitude (twice: m_{high} = 3.93, sd = 0.39; once: m_{high} = 3.92, sd = 0.90) than learners with low ($p < 0.01$, $0.16 < r < 0.25$) and medium educational capital ($p < 0.01$, $0.14 < r < 0.16$).

These differences by educational capital intersect with gender across both samples, with the largest effects arising between male learners with high ($m_{\text{m-high}}$ = 4.08, sd = 0.37) and low educational capital ($m_{\text{m-low}}$ = 3.46, sd = 0.47 $p < 0.01$, r = 0.29) in the sample surveyed twice. In the sample surveyed once, about equally large

[6]The results of all group-based comparisons can be found in the **Supplementary Material** to this article.

effects can be found between male ($m_{m\text{-}high}$ = 3.95, sd = 0.89) and female learners ($m_{f\text{-}high}$ = 3.91, sd = 0.91) from highly educated families when compared with female learners with low educational capital ($m_{f\text{-}low}$ = 3.27, sd = 1.23, $p < 0.001$, $r = 0.29$).

In total, 15% of the learners in the sample surveyed twice (n = 724), and 19% of the respondents surveyed once (n = 724) do not consider science being a part of their identity, i.e., they do not identify with science. This non-identification with science does not significantly vary with time or age. However, also with this dimension of science identity it is the educational capital that significantly influences a learner's probability to non-identify with science, with the largest effect being between learners with low educational capital backgrounds (twice: m_{low} = 3.13, sd = 0.56; once: m_{low} = 3.03, sd = 1.23) and respondents from highly educated families (twice: m_{low} = 3.93, sd = 0.38; once: m_{low} = 3.63, sd = 1.08), (with significance levels $p < 0.01$, and effect sizes between $0.25 < r < 0.26$). While no significant gender-based differences were found at a general level, we see an impact of gender identity within groups of learners, with male learners from highly educated backgrounds being the least likely to non-identify with science (twice: $m_{m\text{-}high}$ = 3.9, sd = 0.37; once: $m_{m\text{-}high}$ = 3.75, sd = 1.00).

In contrast to general science attitudes, measured by the two indices of a positive science attitude and the non-identification with science, the attitudes towards science lessons in school neither vary significantly by educational capital nor gender. About two thirds (67%, n_{twice} = 656; 65%, n_{once} = 698) of all surveyed learners perceive their science lessons in school positively. Among the sample surveyed twice, younger learners are more likely to enjoy their science classes than older ones ($p < 0.001$, $0.22 < r < 0.33$), with the largest effect between the youngest ($m_{8–11\ years}$ = 4.23, sd = 0.47) and the oldest age groups ($m_{18–21\ years}$ = 3.5, sd = 0.52, $p < 0.001$, $r = 0.33$). No such effects are visible among the group of one-time surveyed learners.

Engagement in Science Related Activities

An investigation of activities, learners engage in out-of-the-classroom settings, which might foster informal (science) learning shows group-based differences based on age and gender. In general, 23% (n_{twice} = 735 and n_{once} = 727) of the learners indicated that they engage in self-directed science learning activities at least once a week (a score of 3 or 4 on the constructed index) and about one third (32%, n_{twice} = 735) of the two-times surveyed learners, and a quarter (25%, n_{once} = 731) of learners surveyed once engage at least weekly in arts-based activities which can potentially foster science learning.

Across both samples, male learners are more likely to engage in self-directed science learning ($p < 0.001$, $0.14 < r < 0.20$). This gender-based difference is stronger at an early age as depicted in the data from the sample surveyed twice ($p < 0.05$, $r = 0.31$), but is also present among male and female teenagers in both samples ($p < 0.01$, $0.19 < r < 0.22$). Gender-based differences in self-directed science engagement also intersect with educational capital; male learners from high education backgrounds are, on average, most likely to engage in self-directed science learning (twice: $m_{m\text{-}high}$ = 2.12, sd = 0.41; once: $m_{m\text{-}high}$ = 1.92, sd = 0.9). Their probability to do so significantly differs from female learners of all educational strata, with the strongest effects found in the sample surveyed twice, comparing them with female learners with high educational capital ($m_{f\text{-}high}$ = 1.53, $p < 0.001$, $r = 0.34$) or medium educational capital ($m_{f\text{-}med}$ = 1.52, $p < 0.001$, $r = 0.34$).

In contrast, female learners are more likely to engage in arts-based activities which can potentially foster science learning ($p < 0.001$, $0.17 < r < 0.18$). Introducing information on the educational capital of the learners, we see learners from highly educated backgrounds significantly engage more often in arts-based science learning activities in both samples ($p < 0.001$, $0.22 < r < 0.33$). The combined analysis of educational capital and gender demonstrates that gender differences do not manifest among learners from low educated households, but among learners with medium (twice and once, $p < 0.01$, $0.22 < r < 0.23$) and high educational capital (once, $p < 0.05$, $r = 0.19$). Interestingly, the engagement in arts-based learning is the only form of engagement showing significant changes over time. Between wave 1 and wave 2, learners aged from 8 to 11 increased their engagement in arts-based activities ($m_{twicew1}$ = 1.74, sd = 0.45 to $m_{twicew2}$ = 1.97, sd = 0.45, $p < 0.001$, $r = 0.25$). These changes are particularly attributable to male learners ($m_{twicew1}$ = 1.39, sd = 0.40 to $m_{twicew2}$ = 1.57, sd = 0.40, $p < 0.001$, $r = 0.20$), thereby decreasing overall gender differences ($r_{twicew1}$ = 0.20 to $r_{twicew2}$ = 0.17, $p < 0.001$). Reasons for these changes can, however, only be hypothesized.

Importance of Science in the Learners' Social Environments

Parents play a major role in the learners' engagement with science related activities in a broad sense (Falk et al., 2016): 90% of the learners in the sample surveyed twice and 88% of those respondents surveyed only once indicated that their parents encouraged them to engage in at least a quarter of all specified science-related activities. About one third of the surveyed learners also indicated that siblings (twice: 37%, once: 40%) and grandparents or other relatives (35%) encouraged them to engage in broadly science-related activities. Considering the general social environment of the learners, one can deduce that friends (twice: 63%, once: 51%) are perceived to be more supportive in science-learning than siblings and grandparents. In relation to the results of our regression model, support may have positive as well as negative effects on young learners' science attitudes.

Given the important role of parents for individual learning ecologies a further investigation of parental science relevance was pursued. In contrast to questions of support structures elaborated above, these questions literally addressed the concept of science. Asked, whether science is present in their homes more than a third of the respondents answered that science does play an important role in their family (twice: 33%, once: 36%), while roughly an equal share of respondents (twice: 37%; once: 35%) indicated that their parents are not interested in science.

In line with earlier findings (e.g., Archer et al., 2012) our results confirm the influence of educational capital on science relevance in the learners' homes; with learners with a high educational capital being more likely to perceive science as an important part of their home cultures than learners with medium and low educational capital (twice $p < 0.001$, $0.22 < r < 0.24$; once: $p < 0.01$, $0.13 < r < 0.18$). From an intersectional perspective, the strongest effect in the sample surveyed twice can be identified when comparing female learners with low educational capital ($m_{f\text{-low}} = 2.51$, sd = 0.51) to male learners from highly educated backgrounds ($m_{m\text{-high}} = 3.35$, sd = 0.46, $p < 0.001$, $r = 0.30$), where the latter regard science as being embedded in their homes. The intersectional gender-educational-capital-perspective does not yield significant results in the sample surveyed once. As gender distributions were comparable among the samples, this suggests that primarily educational capital and not so much the gender aspect influences whether science is perceived as an important part of a learner's home-culture.

In addition, age was found to be influential when investigating science relevance at homes; with younger learners reporting a significantly higher presence of science in their homes than older ones ($p < 0.05$, $0.14 < r < 0.18$). Differences by age might be related to changing parent-child interactions: once children grow older, they become more independent and more certain about their own interests. This correlates with findings from educational studies (Barron 2006; Stangl, 2021) suggesting that peers become more important for teenagers, while parental perspectives are likely to get scrutinised once children grow older.

In general, friends and peers represent an important element of a young person's science learning ecology (Bevan 2016). More than a third of both samples (38%, $n_{\text{twice}} = 716$; 39%, $n_{\text{once}} = 719$) indicated that their close friends enjoyed science. With regard to their peers' science attitudes, we see group-based differences by gender and age. Among the two-times respondents, the youngest age group of 8- to 11-year-olds ($m_{8-11} = 3.40$, sd = 0.62) is on average most likely to have a science-positive peer environment which significantly differs from the 12 to 14 age group ($m_{12-14} = 2.86$ sd = 0.62, $p < 0.001$, $r = 0.23$). Across both samples, young male learners below the age of 12 are significantly more likely to have friends interested in science, than female teenagers above the age of 12 ($p < 0.05$, $0.15 < r < 0.19$). The sample surveyed twice additionally depicts significant, yet small differences by educational capital: Learners from highly educated backgrounds are slightly more likely to have friends who have a positive attitude towards science ($m_{\text{high}} = 3.21$, sd = 0.60) than learners from medium ($m_{\text{med}} = 2.94$, sd = 0.59, $p < 0.05$, $r = 0.12$) and low educational households ($m_{\text{low}} = 2.84$, sd = 0.76, $p < 0.05$, $r = 0.13$).

In summary, to answer the questions leading to this chapter: Who are the young learners who positively connect with science? The results of the comparisons highlight the hierarchical relation between gender and the impact of educational capital, with low educational capital affecting young learners' possibilities to connect with science more strongly than gender. However, the intersectional approach has made the variations between young learners with lower and higher educational capital visible, illustrating that even though gender and educational capital both impact the probability of developing a positive science attitude that favor male learners from highly educated backgrounds, it is not female, but male learners with low educational capital exhibiting the lowest probability of developing a positive science attitude. When it comes to engagement in specific forms of science learning, gender seems to be the main structuring influence with male learners being more likely to engage in self-directed science learning while female learners are slightly more likely to engage in arts-based learning.

DISCUSSION

In this paper, we have investigated how to explore the gradual spectrum of unequal opportunities of young learners in connecting with science. We analyzed science learning ecologies by applying an intersectional perspective that allows for a fine-grained understanding of factors impacting equity in science learning that does not blame single individuals for their "deficits," but rather explores underlying structural inequalities shaping individual learning ecologies (Annamma and Booker 2020). Empirically, we first investigated the isolated effects of parameters influencing the development of a positive science attitude. Following the theory of learning ecologies, socio-demographic information, data on the learners' social (support) structure, their engagement and their experience of school science lessons were integrated into the model. Secondly, we looked at intersecting group differences between young learners' science attitudes and non-identification with science, the ways of engaging in activities potentially fostering science learning and their related social context, focusing not only on age, gender and educational capital, but also on their intersecting effects.

Interestingly and contrary to the findings of earlier studies, in our investigation neither educational capital, gender nor migration histories by themselves turned out to significantly improve the logistic regression model of positive science attitude development, outlining instead the importance of the learners' own motivation and of their attitudes towards science learning in school. This is not a new finding, but e.g., supported by Barmby et al. (2008) who argue that science learning in school has a high influence on the formation of positive science attitudes and therefore represents a crucial point for strengthening young learners' science attitudes. The results of our regression model hence demonstrate the value of applying the theoretical lens of learning ecologies conceptualising science learning as a culturally and socio-spatially embedded process across different learning contexts when investigating the way learners connect with science (Barron 2006). Even though schools are a place where the dominant concepts of science learning are reproduced, following a prescribed curriculum and (gendered) educational principles most congruent with the norms and conventions of highly educated middle-class families (Bourdieu 2001; Goldthorpe 2007), in our study no significant differences by gender and/or educational capital were identified using comparisons of means. The significant effect of school involvement for selecting survey participants, however, might add a possible explanation: Three quarters of our respondents were engaged using existing collaborations between schools and our partner organisations–museums, science centers or maker spaces offering non-formal science education. The significant effect might hence be not so much related to the equitability of formal education in general, but rather to these existing partnerships, which make formal as well as non-formal science education more accessible to all the students of a classroom. However, the strong impact of science lessons in school also suggests a high responsibility, as these school science experiences largely impact the science learning ecologies of students in a positive as well as a negative way which can cause lasting non-participation (Dawson 2012).

In contrast to the regression model, the intersectionally operationalised comparisons of means indicate the persisting effects of educational capital on the learners' science attitudes, non-identification, parental science relevance and the learners' regular engagement in activities, which potentially foster informal science learning. Despite our use of the order-sensitiveness of the stepwise regression model (Field et al., 2012), the (combined) effect of educational capital and gender might have equally influenced the other independent variables and therefore did not turn out statistically significant themselves. An example for this effect is the positive correlation of engaging in arts-based learning and positive science attitude development found for the sample surveyed once. While there are studies suggesting a direct relationship between cognitive processes of engaging with arts and music, such as enhancing creative thinking (Braund and Reiss 2019), spatiotemporal ability (Črnčec et al., 2006), and the learners' motivation, self-confidence or perseverance (Winner and Cooper 2000), observed empirical correlations between engagement in arts and learning achievements can also be largely attributed to educational capital (Winner and Cooper 2000; Črnčec et al., 2006; Hille and Schupp 2015); learners from more educated families are more likely to get engaged in extracurricular activities entailing arts-based learning. Also, among our surveyed participants the availability of music instruments in the learners' homes positively correlates with their educational capital across both samples. From the comparisons of means, we equally see intersecting effects of educational capital and gender. Since arts-based learning positively influences the likelihood to develop a positive science attitude among the one-time respondents–our more representative sample–we can assume that effects of educational capital, which obtained a p-value of 0.079, might have turned out significant in the regression analysis, if sample size was bigger. This is, however, not the case for the sample surveyed twice, where the effect of educational capital obtained a p-value of 0.778. One possible explanation for this stark difference between samples might be related to effects of self-selection among double-surveyed learners, who exhibit extremely positive science attitudes in general. For the sample of learners who participated twice (possibly smaller) effects of educational capital–potentially–condense in the independent variable of parental science relevance, suggesting that their home culture is among the most important factors explaining their probability to develop a positive science attitude, hinting at distinct support structures that shape their science learning ecologies. This is supported by former studies suggesting a positive impact of parental support on academic achievement of the learners of all classes (Gorard and See 2009). However, available resources for supporting the learners, such as time, again vary with socio-economic status of the parents (Jordan 2010). The comparatively lower support among the learners only surveyed once in our study, might have stipulated the higher importance of the learners' own motivation and own interest to engage in science for the formation of a positive science attitude. The negative effect of supportive siblings found in both samples is interesting, yet not explainable from our results and needs further investigation, exceeding the scope of this paper.

While the results of the regression model put the focus on the individual learning ecologies (learning experiences in school, engagement in learning, development of science attitudes over time), the group comparisons provide more detailed analyses of the effects of unequal learning opportunities, introduced and (re-) produced by the prevailing normative concepts of science. The results of the group comparisons empirically support the findings of former studies carried out in other socio-cultural and geographically influenced regions (mainly the United Kingdom and US) and prove their validity also in the European context. Examining our findings more closely from an intersectional perspective enabled us to not only look into inter-categorical differences by educational capital *or* gender but visualised the many ways both intersect when shaping individual engagement and science learning (Harnois 2013). Social identities "interact to form qualitatively different meanings and experiences" (Warner 2008, 454) adding together to shape experiences over time (ibid). Importantly, these specific manifestations cannot be reduced to single elements analytically, as living realities are constantly shaped by the intersections of dimensions of social inequalities (Bowleg 2008).

Our findings on gender-based differences, differences by educational capital and on their intersections underline the importance of investigating the fine-grained influences of diverse group identities as aspects of individual science learning ecologies. Supported by the intersectional design, the results highlight the role of educational capital on the formation of positive science attitudes and a strong influence of parents on the engagement in science related activities can be observed. This influence becomes less important when young learners grow older, with peers potentially taking over their role (Stangl, 2021). The results of the comparisons also underline the potentially positive effect of the prevailing gendered understanding of science which supports male learners with high educational capital to positively connect with science.

In line with the findings of other researchers (e.g., Carlone and Johnson 2007; Archer et al., 2014; Annamma and Booker 2020) our findings suggest the need to diversify science learning to allow all learners to positively connect with science (Durall 2020). To overcome persisting inequalities, more equitable science learning spaces and offers have to adapt to a diversity of needs and preferences in order to make science activities enjoyable for all (Annamma and Booker 2020; Voigt et al., 2020).

The intersectional approach attempts to open the perspective to an integrated vision of the formation of social identities, including different aspects of social identities. These concepts influence how the formation of individual science ecologies can be investigated: They pinpoint the methodological limitations of an empirical research that has to decide which intersections of identities will be investigated in advance (Warner 2008). However, and importantly, this difficulty is not only related to the intersectional approach, but also to the concept of science identities (Carlone and Johnson 2007; Steinke 2017). Since unveiling, analysing and ultimately changing inequalities lie at the heart of the concept of intersectionality, the approach gives some guidelines about necessary structural -not individual–dimensions that need to be addressed (Annamma and Booker 2020). This is also why intersectionality might offer a useful conceptual frame for science identities to investigate their dimensions, relationality, and multiplicity (Avraamidou 2020). As much as the decision to focus on specific structural inequality leads to the necessary exclusion of other factors, the focus on gender-identities, educational capital, age, and their intersections selected on the basis of the collected data and the existing literature in this field, this paper provides evidence and exposes the negative effects of the narrow dominant concept of science learning.

For investigating science learning from an intersectional perspective, a diverse sample of respondents is needed that allows for large-enough group sizes, once subgroups are formed and need to be embedded in data collection, sampling procedures as well as methods for data analyses (Bauer 2014; Rouhani 2014; Seebacher 2016). While this approach had been taken into consideration from the very beginning of the research at hand, our operationalisation was limited by practical possibilities of the project setting: From an intersectional perspective it would have been fruitful to be able to analyze gender beyond a binary male-female self-identification (Traxler et al., 2016). Based on the low numbers of respondents identifying beyond the gender binary, only binary analysis of gender could be made. While operationalised, the strong context dependency of migration experiences potentially hindered the index from working equally well for all of the surveyed groups (Harnois 2013). Based on empirical evidence for different contexts, also the dimensions of race/ethnicity (Hazari et al., 2013) and dis_abilities (Bell et al., 2009) should have been included more strongly in the survey, the sampling strategy and the analysis, which however, exceeded the abilities of the study at hand. Future research investigating persisting inequities in science learning are, however, strongly recommended to do so.

Despite not succeeding in overcoming all challenges of embedding intersectionality in a quantitative framework, our two-step methodological (regression analysis followed by comparisons of means) and theoretical approach (integrating the concept of learning ecologies and an intersectional approach), has succeeded in showing the diverse and complex ways young learners' science ecologies are shaped.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: AUSSDA (https://aussda.at/en/) DOI https://doi.org/10.11587/MG9VQK

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Center for Social Innovation, Linke Wienzeile 246, 1150 Vienna. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

LS has collected the data and lead on the data analysis, IV has substantially contributed to the article, both of them share first authorship. CV and JT have provided feedback and helped to systematise the article.

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Sustainability, Spread, and Shift: Developing a Professional Learning Program for Out-of-School Educators With Scale-Up in Mind

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This case study describes the iterative process used to develop a virtual coaching program for out-of-school-time (OST) educators, particularly those who work in afterschool and library settings. The program, called ACRES (Afterschool Coaching for Reflective Educators in STEM), used a design-based implementation research (DBIR) approach to consider issues related to scale-up. Afterschool and library settings are complex systems that include supports and barriers that require adaptation for implementation. Throughout the design process, program developers worked to identify the essential elements of the program that should be maintained across contexts, while attending to the diverse needs of individual OST settings. Survey and interview data were collected from the full range of stakeholders throughout the implementation process to verify the importance of the essential elements to the professional learning model, and to gather early indicators of the program's potential related to three key concepts for successful scale-up of programs: sustainability, spread, and shift. Conclusions are shared in relation to how these types of results support the scale-up of programs, and the strengths and gaps in the process used to apply the DBIR approach in our work.

Keywords: out of school, professional learning communities (PLC), design-based implementation research, scale-up, instructional coaching

INTRODUCTION

After a successful initial implementation period, one of the primary goals of innovative educational programs is to scale up, or to be implemented across a number of diverse educational contexts. The motivation for scaling up is the hope that sharing the innovation widely will improve teaching and student learning throughout a system (Fullan, 2009; Peurach and Glazer, 2012). However, this is often a challenging feat for new educational programs (Levin, 2013; DeWire et al., 2017), especially considering the dynamic, complex needs of each unique educational setting within the system. This can be especially true for OST programs that often have more variability across setting and less consistency in youth attendance when compared to K–12 classrooms.

While some define scaling up simply as "more" (i.e., implementation in more schools or programs, with more teachers and more students), others recognize the multifaceted nature of scaling up (Coburn, 2003; Dede et al., 2007). Coburn states that the process is complex, and includes four interrelated elements: depth (changes in beliefs, norms, and pedagogy), sustainability (change that is maintained over a substantial period of time and is supported at multiple levels), spread (dissemination both within and across organizations, which in turn influences policy and decision-making), and shift in reform ownership (ownership is assumed by users and is adapted as necessary to fit the unique needs of the organization).

One research method that is particularly well-suited to help innovative educational programs achieve scale is design-based implementation research (DBIR) (Penuel and Fishman, 2012; Penuel et al., 2011; Fishman et al., 2013; Svihla, 2014). The process of DBIR allows researchers to work in collaboration with multiple stakeholders to improve and appropriately adapt educational programs as they scale across diverse educational settings. The four core principles of DBIR are: 1) a focus on solving practical problems, as determined by multiple stakeholders; 2) a collaborative, iterative design process in which stakeholders are consulted and provide valuable input; 3) the goal of creating knowledge to be used in various learning contexts, which can also serve to improve design; and 4) a focus on increasing capacity to help educational innovations spread throughout an entire system or organization. Working in conjunction with one another, the four elements of DBIR allow researchers to both develop innovations *and* evaluate and refine innovations such that they are positioned to scale (Penuel and Fishman, 2012; Cobb et al., 2013).

In this case study, we describe the development of, and early implementation research on a virtual professional development program for OST educators called ACRES (Afterschool Coaching for Reflective Educators in STEM). We share data that were gathered iteratively to improve the ACRES program in collaboration with multiple stakeholders. We also demonstrate how, using DBIR, ACRES is poised to scale up based on the dimensions of sustainability, spread, and shift. This study is unusual in that DBIR was employed to iteratively revise and improve a professional development program designed to support OST educators in informal learning environments. Historically, DBIR has been used to refine educational programs implemented in traditional school settings. At the time of this writing, the authors could identify only two studies to date that have used DBIR to make enhancements to informal learning programs (Patchen et al., 2017; Subramaniam et al., 2021).

The Need for Virtual Professional Development for Out-of-School-time Educators

In the United States, community professionals such as afterschool providers and librarians are increasingly being asked to provide youth in their communities with hands-on STEM learning experiences. A recent study found that STEM activities were offered at over 70% of all programs (Afterschool Alliance, 2020). In libraries the growth has been more recent but dramatic: in 2016, 55% of libraries reported offering STEM programming at least monthly (Hakala et al., 2016), while in 2019 that percentage had risen to 70% (Shtivelband et al., 2019). At the same time, research suggests that the majority of OST educators do not have strong backgrounds in STEM (Chi et al., 2008), leading to repeated calls for professional learning opportunities (e.g., National Research Council, 2015; Rosa, 2018). A recent study in 11 states showed that participation in STEM-focused afterschool programs leads to increases in youth STEM interest, identity, career knowledge, and 21st-century skills such as critical thinking. Even more importantly, these gains were higher in youth who participated in higher-quality programs, as assessed using the Dimensions of Success (DoS) observation tool, which includes key facilitation practices such as encouraging youth to engage in STEM inquiry and to explain their new understandings (Allen et al., 2017).

Persistent Problems of Practice

In this DBIR work we focus on two problems of practice that are frequently faced by OST educators in relation to their growing roles as STEM educators: 1) Despite the demands on them to offer high-quality STEM programming, they are in systems that rarely promote investments in their professional learning to support this goal. STEM activities tend to be "hands-on" without being "minds-on," and there is seldom a culture of reflection on STEM education practice to encourage the deeper learning characteristics of high-quality STEM programs (Allen et al., 2017); 2) These community educators often experience professional isolation, especially in rural areas. Clearly there is a need for high-quality, accessible professional development in a socially supportive context. The use of group coaching models, preferably conducted virtually, seem particularly promising in addressing this need (Denton and Hasbrouck, 2009; Brasili and Allen, 2019).

The Program's Theoretical Framework

The underlying theoretical framework for ACRES draws from research and practice in three subdomains: instructional coaching, professional learning communities, and contemporary digital technologies. Each was explored in action during the pilot years of the program.

Instructional coaching is a relatively common strategy in the world of school-based teacher professional development (Denton and Hasbrouck, 2009). In this approach, a skilled leader helps teachers learn and apply new teaching strategies in their own work, in an atmosphere of collaboration and reflection. While much still remains unstudied in this area (Blazar and Kraft, 2015), some have shown its power to improve teacher practices and student achievement (Sailors and Price, 2010; Allen et al., 2011; Campbell and Malkus, 2011). One finding is a strong correlation between the amount of time the teacher and coach spend together and improvements in practice (Anderson et al., 2014; Blazar and Kraft, 2015). From this literature, the project team determined that the course would explicitly focus on a small number of STEM facilitation skills. Additionally, the program is based on the well-established principle that learning skills takes time and practice, making it quite different from single professional development workshops (e.g., Garet et al., 2001).

A second major development in the world of school-based teacher professional development is the use of professional learning communities (PLCs) in school districts across the

TABLE 1 | The eight ACRES modules.

1. Asking Purposeful Questions	A foundational skill that involves eliciting student thinking and broadening or deepening that thinking by asking various forms of open-ended questions Michaels and O'Connor (2012), Michaels and O'Connor (2015).
2. Virtualizing your Programs and Activities	Using a range of technologies and pedagogies to keep youth socially and cognitively engaged in virtual STEM programs.
3. Modeling Engineering Practices	Emphasizes girls' development of an engineering mindset. Popular in response to the Million Girls Moonshot initiative.
4. Giving Youth Voice and Choice	Letting youth make the design decisions, from a simple constructed object to a full community engagement project.
5. Modeling Science Practices	Supporting youth to practice the skills of NGSS.
6. Integrating Math Practices	Integrating mathematics into daily activities, emphasizing measurement, estimation, and having a growth mindset.
7. Nurturing STEM Identity and Careers	Making activities relevant to youth's lives, encouraging them to identify STEM in daily situations and imagine future STEM careers.
8. Understanding Youth Thinking	Methods of doing embedded and non-intimidating formative assessment of what youth are learning.

country (e.g., Sims and Penny, 2015; Spencer, 2016). Essentially, a PLC involves a group of educators coming together with a common set of goals to reflect on and improve their teaching practices (Blankenship and Ruona, 2007; Britton et al., 2010). Research has shown the power of PLCs to change teacher practices, such as paying more attention to students' reasoning, and using diverse modes of engaging students (Britton, 2010; Owen, 2015; Gee and Whaley, 2016), skills that would translate extremely well to the OST world. While PLC's take a variety of forms, research by Nelson (2009) has shown that key elements for success include: teachers taking a learning stance in their work together, a nurturing and supportive environment, and targeted support in the topics of greatest challenge. The project team applied this literature to the general format of the program to create instructional PLCs, which included an ongoing series of meetings with peers, focused on creating a supportive culture of reflective practice. Additionally, the program encourages an explicit focus on educators engaging together dialogically as learners and integrates principles of focusing on what students are thinking and learning.

The third component of the model is the use of inexpensive digital recording and communications technologies to make the instructional PLCs work for blended or fully online groups of educators, without the need to purchase additional hardware. Video recordings of educators' interactions with youth are shared privately with peers during the instructional PLC, and effectively simulate a live coaching scenario (Sherin and Han, 2004; Gaudin and Chalies, 2015; Cook et al., 2021). Improved video conferencing platforms such as Zoom and Google Hangout, now ubiquitous, allow for an online experience that can be made highly social and interactive (Brasili and Allen, 2019; Peterman et al., 2020).

When the first pilot version of the project began in 2014, these tools were used rarely for OST professional development. Now, as the result of the COVID-19 pandemic, they are used more frequently. Even so, while online learning has been championed largely by universities (including the use of MOOCs, webinars, and asynchronous approaches), and PLCs or instructional coaching are increasingly being used in school districts, this particular combination was unique in OST professional development when the program was initiated. It still serves as one of only a few examples in the literature today.

Study Context and Early Iterations

Over time, the project was refined to include a series of professional learning sessions in which three to 10 educators meet synchronously online every two to six weeks with a coach to learn and practice STEM facilitation skills for leading OST programs with youth. Over the course of three sessions, a coach teaches and models skills in the context of a hands-on activity, and participants watch sample videos of other educators using the skills. They then bring videos of their own work with youth to share with their cohort, and practice sharing constructive feedback by discussing strengths and opportunities for growth in each video.

The program consists of eight modules, each of which targets a STEM facilitation skill (see **Table 1** for a full list and descriptions of each).

The DBIR approach (Fishman et al., 2013) was used to develop the program, and provided insight into how the innovation works under a wide range of OST settings. Multiple OST stakeholder groups came together, for example, to inform the design and delivery of the program in response to persistent problems related to the need for professional learning in highly effective STEM pedagogies, especially across distance. Stakeholders included staff from the Maine Mathematics and Science Alliance, with expertise in design of professional learning experiences in STEM; leaders from the National Afterschool Association, and from state and national library associations, with STEM interests and deep experience in professional learning for their members; educational researchers specializing in OST teaching and learning; and both leaders and practitioners from a wide range of afterschool and OST settings. They met in various configurations; most common were weekly meetings among the five MMSA coaches to share experiences and suggest improvements to the model, large-group advisory meetings held approximately three times a year, and myriad one-on-one conversations between MMSA staff and specific professional groups (e.g., Vermont Afterschool Association, Maine Afterschool Network, and New York State 4-H Youth Development) during preparatory customization of the program to meet the needs of their particular professional group. Ongoing data collection was also used to support iterative decision making.

As noted earlier, DBIR focuses on improving learning environments for students, building capacity for educators to enact innovations, supporting systems-level improvements by focusing on both the design of tools and practices, and designing supports for using those tools and practices in real-world settings. In the context of this case study, the program was developed to build the capacity of OST educators to facilitate STEM activities

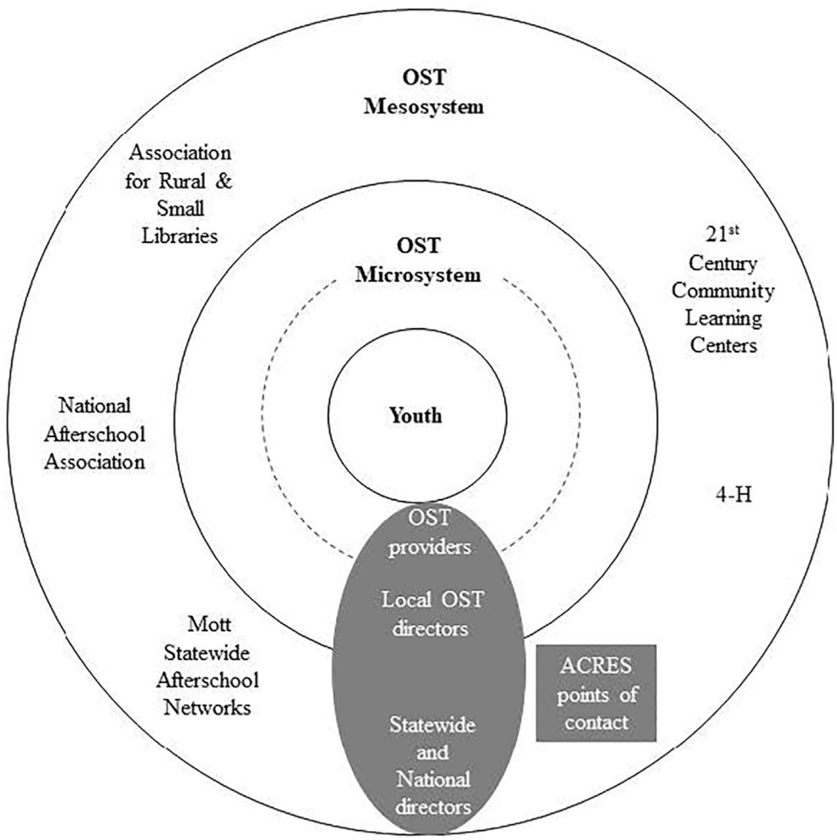

FIGURE 1 | Adaptation of Bronfenbrenner's ecosystem model to show the OST contexts where ACRES has been implemented, and the levels at which ACRES interacts directly with stakeholders in the OST system.

with youth, thereby improving the learning environment for students. By building OST educators' facilitation skills and confidence, the program provides tools to offer youth hands-on, minds-on learning experiences that nurture STEM relevance and identity, and deepen reflection and understanding, while engaging in authentic STEM practices (Cook et al., 2021).

Figure 1 presents the OST learning ecosystem in which the program operates and includes examples of the key stakeholders with whom the program has direct interaction in gray. These include OST educators who work directly with youth and local OST directors, both of whom are in the microsystem, as well as national offices and support networks in the mesosystem. Two levels of stakeholders are represented in the microsystem, with OST educators who are positioned closer to youth and OST directors who are positioned closer to the mesosystem.

The specific groups presented in the mesosystem of **Figure 1** include those who participated in the program from 2017 to 2020, including a total of 816 educators. **Figure 2** shows the geographic reach of ACRES programming to date. The program has reached educators in 44 states, with the most concentrated reach in the Eastern U.S. Many educators signed up and participated as individuals, but some knew each other as a result of being actively recruited by a common contact such as a supervisor.

The majority of educators represented in **Figure 2** participated in Asking Purposeful Questions and Virtualizing Your Programs and Activities, the two modules featured in this paper; a total of 802 educators have completed one or both of these modules to date (98%). ACRES educators are described in more detail in **Table 2**. Regarding geographical setting, the largest demographic was from rural areas which has been a particular focus for the program. Most educators work with youth in afterschool programs or club settings, while smaller numbers engaged with youth through libraries, summer camps or other informal learning environments.

The spread of the program was also aided by the frequent offering of "Taster Workshops," 45–1.5°h-long during which interested educators were given a short experience with the program's materials and pedagogical approach. These reached a total of 1,414 over the same period (see **Figure 3** for a comparison). The Taster Workshops were particularly helpful as a strategy for showing that the course was enjoyable and social, and for beginning to build early relationships between educators and coaches.

The program was developed with a focus on scale and sustainability from the beginning. It was unique in that professional learning was offered to the full range of OST systems concurrently, rather than working within one OST system (such as statewide afterschool networks) and then expanding to another (such as 4H). Project recruiters

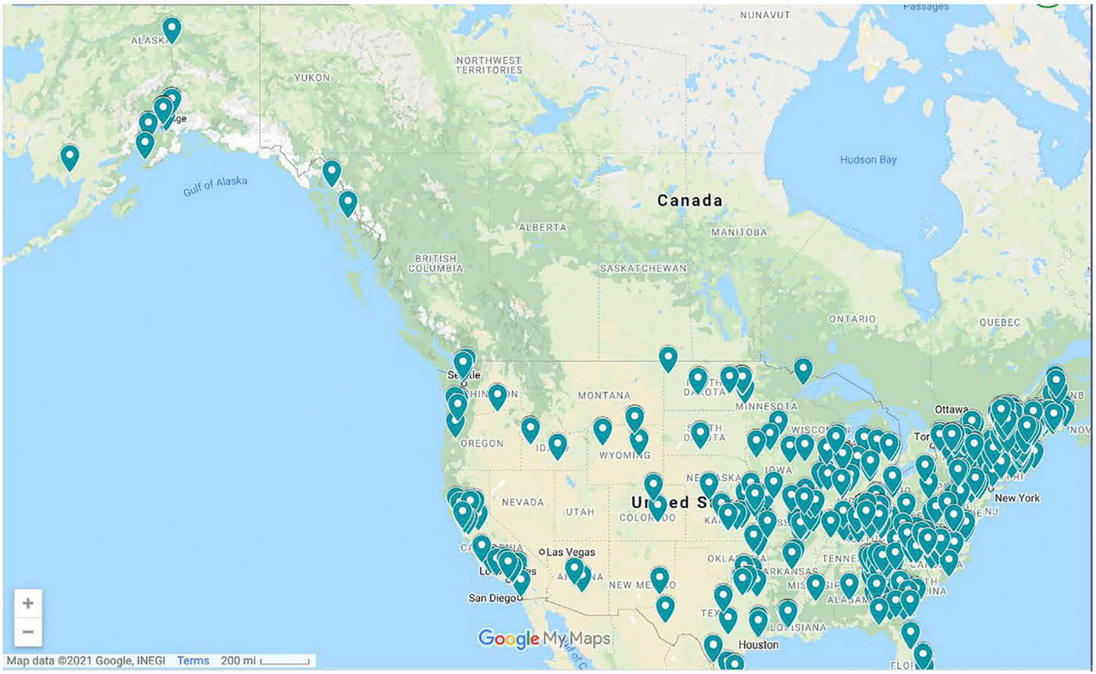

FIGURE 2 | Geographic spread of ACRES educators.

TABLE 2 | ACRES educators by region, geographical and Educational setting.

	Purposeful questions	Virtualizing	Both
U.S. Region	N = 628	N = 103	N = 55
Northeast	52%	29%	31%
South	20%	64%	35%
Midwest	17%	1%	13%
West	10%	5%	20%
Geographic setting	N = 379	N = 102	N = 46
Rural	46%	39%	41%
Urban	32%	34%	22%
Suburban	22%	26%	37%
Educational setting	N = 625	N = 103	N = 55
Afterschool program/club	72%	66%	82%
Library	12%	5%	16%
Youth camp	10%	10%	16%
Child care Center	4%	1%	—
Other	11%	39%	13%

Data were reported via registration pages and surveys that were refined over time. The differences in sample size are due mostly to these revisions and questions being added at a later date in the program's history.

attempted to initiate extended relationships with OST organizations from the beginning and created supportive pathways for educators to become coaches within their own organizations. The team also considered processes that would support the program's implementation within the context of each OST system, such that an entire network or region might implement, scale, and sustain the innovation. As with all DBIR projects, key questions of interest included *What works for whom and under what conditions?* and *How can we make this innovation work under a wide range of conditions?* (Penuel et al., 2011; Fishman et al., 2013). With these questions in mind, the program and research and evaluation efforts were devised to understand design and implementation supports and constraints across the OST settings involved, in order to build understanding about virtual professional development for the field.

METHODS

The data for this case study were collected over a two-year iterative development period. Some data were collected consistently over time. Other data were gathered on one occasion and in response to specific design questions relevant to the current stage of the program's development. Analyses were conducted regularly as data were collected so that they could be used as part of the DBIR process. Results are presented here in aggregate, and from professional audiences from the range of OST stakeholder groups included in gray in **Figure 1**.

Participants

A full range of project stakeholders contributed data to support the iterative development of the program across a two-year implementation period. **Table 3** presents a summary of participants, methods, and timing of data collection by stakeholder group. Qualitative data were collected from both program recruiters and OST program directors. Program recruiters are the people tasked with establishing new cohorts of educators to participate in the program. Four interviews were conducted in fall 2019 to gather stories about recruitment successes and challenges in afterschool settings. A second

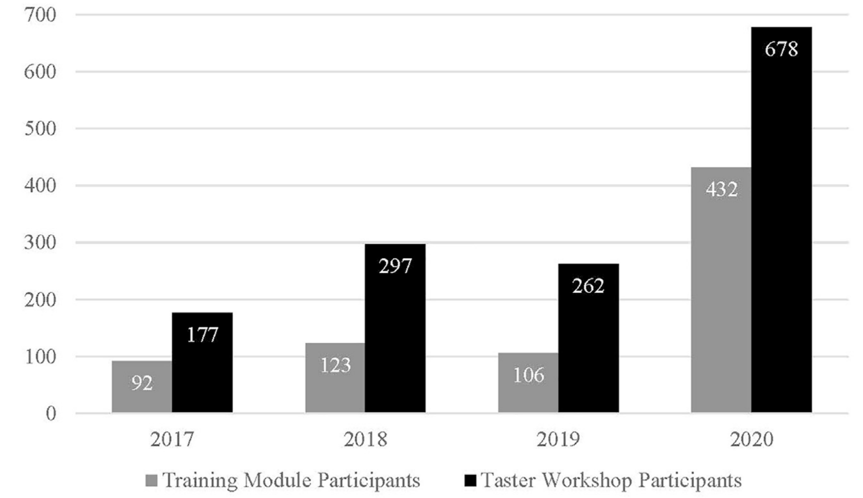

FIGURE 3 | Program participants over time, by program type.

round of five interviews was conducted in early 2020, with a specific focus on those who had recruited and worked with library cohorts.

In spring 2020, interview data were collected from the six statewide OST directors who had begun to embrace the program; this number represented the majority of statewide afterschool networks that had participated in the program at that time. These directors were chosen in collaboration with the program staff to represent those who showed significant interest in the program, and various degrees and timeframes of participation.

Qualitative data were also collected from coaches-in-training. All coaches who participated in a train-the-trainer program in fall 2018 were invited to participate in an interview to share their feedback about the program's essential elements in winter 2019; six of 10 participated in the interview (60%).

Quantitative survey data for this study were collected from two groups of OST educators. The first included those who completed a post-program survey after completing the Purposeful Questions module between spring 2019 to the end of 2020; a total of 66 educators completed the survey during that time (referred to hereafter as the Purposeful Questions educators). The second included those who completed a post-program survey after participating in the Virtualizing STEM module (n = 54, referred to hereafter as the Virtualizing educators).

Finally, longer-term qualitative data have also been collected from those in the Purposeful Questions cohorts. All educators who had completed the module between spring 2018 and fall 2019 were invited to participate in a follow-up interview in spring 2020 (n = 59). Of these, 20 responded and were interviewed (34%).

Instruments and Procedures

Four interview protocols, one for each stakeholder group, were used to collect data for this study. All interviews were transcribed for the purposes of analysis. Interviews with recruiters, directors, and coaches-in-training were coded for common themes across the entirety of the interview transcript. The interview protocol for program recruiters consisted of 18 questions designed to identify themes related to the systemic supports and barriers to joining and completing the program. The protocol for OST directors included a minimum of 20 questions. A subset of items included a series of "anything else" prompts that were used to ensure the capture of comprehensive details regarding the systemic barriers and supports for integrating programs into their educational context, and adaptations that were made to the program for implementation purposes. The interview protocol for coaches-in-training included 28 questions; responses were coded to capture impressions of the importance of essential elements of the program.

Follow-up interviews with Purposeful Question educators were coded on a question-by-question basis. Many responses were coded dichotomously, e.g., to characterize the particular configuration of components experienced by participants. A subset of responses were coded thematically, using consensus coding that was conducted by two members of the research team. For the purposes of the current study, responses to 11 items were used to document the systemic supports and barriers to using the program, educators' use of the program's facilitation skills with youth in STEM programs and beyond, the perceived impact of the program on youth, and ways that educators shared their experiences with others in their network.

Each of the quantitative assessments were administered as an online survey at the conclusion of the program. For the purposes of this study, responses to two questions asked of the Purposeful Questions educators were used. One question asked which of the ACRES components Purposeful Questions educators had implemented, and the other asked how likely educators would be to recommend the program to a colleague. Both questions were answered in a Likert-style rating. Similarly, responses from three questions asked of Virtualizing educators were used, all of which were rated on a Likert-style

TABLE 3 | Summary of study methods, by stakeholder group.

Stakeholder group	Timing of data collection	Method	Sample size	Key concepts+			
				EE	SU	SP	SH
OST directors	Spring 2020	Interview	6		✓	✓	✓
ACRES recruiters	Fall 2019–Winter 2020	Interview	7		✓	✓	✓
Coaches-in-training	Winter 2019	Interview	6	✓			
2019–2020 Purposeful questions Educators	Spring 2019 – December 2020	Survey	66	✓	✓		
2018–2019 Purposeful questions educators	Spring 2020	Interview	20		✓	✓	✓
Virtualizing STEM educators	Summer 2020 – December 2020	Survey	69	✓	✓		

+ EE, essential elements; SU, sustainability; SP, spread; SH, shift.

scale. Two of these questions focused on changes in the ways in which Virtualizing educators interact with youth, and the third asked how likely they were to recommend the program to colleagues or friends. All ratings data were scored low to high for the purposes of analysis.

RESULTS

Essential Elements

DBIR derives from the intersection of several research traditions: evaluation research, community-based participatory research, design-based research, implementation research, and social design experiments (Fishman et al., 2013). It acknowledges the fact that programs are embedded in complex systems, and promotes study across multiple levels of a system as part of the design process. As one major part of their DBIR process, the project team utilized The Innovation Implementation Conceptual Framework (Century and Cassata, 2014) to identify and verify the essential elements of the model. Structural components, as defined by this framework, are the organizational, design, and support elements that serve as building blocks for an innovation. Other structural components are educative, in that they are designed to teach participants to know something or be able to do something. In addition to the structural components, the Innovation Implementation Conceptual Framework documents interactional components that explain the behaviors, interactions, and practices of an innovation during a program's enactment.

As part of their DBIR process, the project team met regularly throughout 2017 and 2018 to discuss implementation successes and challenges, and to identify a list of feasible essential elements. As the result of these meetings, the structural components of the program's virtual professional development model (labeled S1–S5 in what follows) were refined to include the following: online instructional PLCs that include a small group (ideally six) of OST educators (S1) who meet regularly with a coach (S2), who teaches and models skills in the context of a hands-on activity (S3). For a minimum of two sessions, the educators are encouraged to bring short videos of their own practice to share with their cohort (S4). The videos are expected to be less than 5 min in length and demonstrate practice using the facilitation skill. Cohort members then practice sharing constructive feedback by observing and discussing strengths and opportunities in each video (S5). Within this structure, the educative components include the information shared with practitioners to define each of the facilitation skills and the ways those skills should be used to lead youth-based OST programs (e.g., What is a purposeful question, and what are ways to integrate purposeful questions into OST activities?).

The program's interactional components are the behaviors that coaches are expected to use when leading the instructional PLC to foster a positive and interactive learning context for OST educators. The instructional components are labeled I1-–I5 hereafter. Specifically, coaches establish group norms and shared goals for the cohort (I1). They reiterate that the project respects the privacy of participants by keeping all videos confidential, and by encouraging transparent sharing of honest feedback from multiple perspectives (I2). Coaches set high but achievable expectations for OST educators during each professional learning session by encouraging practitioners to set "stretch goals" that will help them move beyond their existing skill level and advocating for "safe and brave" space for sharing and receiving feedback (I3). They model skillful facilitation (e.g., asking mostly open-ended questions, modeling wait time; I4), and support technology learning by integrating opportunities into the instructional PLC sessions (I5).

Data were collected over time to document whether and how these structural and interactional elements were considered vital program components to those being trained. The first opportunity was a series of interviews with coaches-in-training that were conducted relatively early in the project team's process to document essential elements. That work, and the interview responses from coaches-in-training, then informed a new set of survey items that were used to gather impressions from both Purposeful Questions and Virtualizing educators. Each group answered questions that were framed to represent essential elements within the context of the specific professional learning module being evaluated. Results are described below for each of these three groups. For the purpose of this analysis, the results reference the specific essential elements identified above (i.e., S1–S5, I1–I5). In reality, none of the essential elements function alone and many are dependent on the others for the program to be successful. Even so, attempting to disaggregate the essential elements to verify their role in the learning process, from the perspective of various stakeholders, proved a useful strategy for the DBIR process.

Coaches-in-Training

Coaches-in-training shared their impressions of the importance of each ACRES essential element based on their experiences with the train-the-trainer model. Most had not yet applied their professional learning to lead a cohort of their own. Coaches-in-training shared unique ways that their coach and their peers

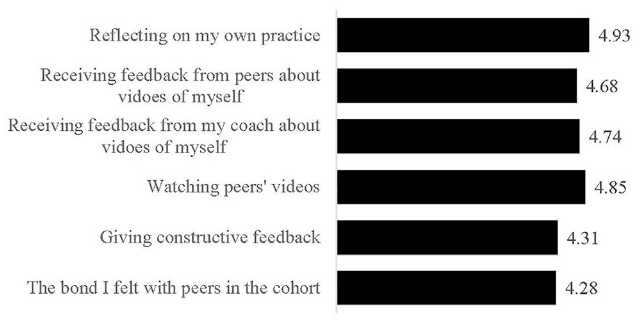

FIGURE 4 | Essentials elements ratings, provided by purposeful questions educators.

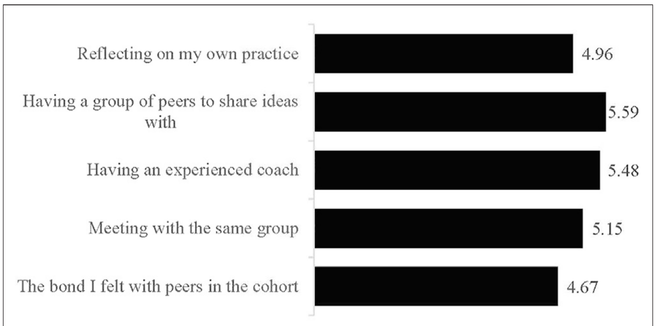

FIGURE 5 | Essential elements ratings, provided by virtualizing educators.

were important to learning how to be a coach, with 83% (n = 5) describing the specific roles that coaches played and 100% describing the influence of their peer group (n = 6). Regarding their coach, coaches-in-training shared general examples about how the coach modeled the program' facilitation skills (S3, I4), as well as specific examples of support provided during the instructional PLC (I1, S4). They believed that the small cohort size (S1) allowed for relationship building over time (S2), overall discussion, and time to dive deeply together into the program materials. Coaches-in-training also reported that live meetings provided a positive and meaningful environment to engage in genuine interactions, while also nurturing fresh ideas. The quotes below reiterate the importance of modeling skills (S3, I4) and creating a safe and brave space (I3) for sharing openly (I2).

> I think (our coach) and the rest of the ACRES team are really great about modeling the skills we're trying to use. So they ask good purposeful questions and make sure that it's up to us to reflect on our work and what we're doing and set a welcoming and inclusive environment so it makes it easy for everybody to chime in.
> I think in a small group you get to know people better. You get to have time to have discussions too. So you can go a little bit deeper sometimes than if it's a larger group. And the comfort. You feel like a team.

Much of the learning that happens in the program occurs through sharing and receiving constructive feedback about videos that feature teaching practice. The video requirement is a primary way that the coach supports technology use (I5). Participants watch sample videos of one another as they use the program's facilitation skills with youth, and then discuss the strengths and growth opportunities observed (S4, S5). Five coaches-in-training (83%) confirmed that having time to reflect on their own practice was a meaningful element of their train-the-trainer experience. Some stated that receiving immediate feedback from peers was meaningful to them, while others focused more on their own thinking and reflection. The quotes below reflect learning that occurred from watching their personal video in one instance (S4), and peer videos in another (S5). Both examples demonstrate coaches-in-training reflecting on ways to stretch their practice (I3).

> It's hard work to sort of unpack your habit. It's definitely hard work to put yourself in the vulnerable position of watching yourself teach and seeing yourself sort of stumble through what you hope is going to be a quality experience.
> Watching the others' videos was very helpful because I could see, "Oh, that's a great idea," or, "Oh, I like the way they engaged the kids with that activity." So I was able to take tips to help with me and with my teaching.

Coaches-in-training also highlighted the bond that is fostered by the instructional PLC, and the role those bonds play in the success of the model. The first quote below highlights many essential elements of the program, reiterating the importance of receiving live feedback in response to videos of teaching practice (S4) and then reflecting on how to apply that feedback (S5). The second demonstrates the importance of the bonds created through the program in contexts beyond, referencing the ways the cohort model provides the opportunity for broad support and collegiality. When asked to reflect on their learning during the train-the-trainer sessions, coaches-in-training shared:

> When you're investing at this level of personal contact, it's such an enormous jump of your skill sets because you are viscerally involved in hearing live someone's feedback to what you produced. And it forces you to sort of step back and say, "Okay, I heard these really nice things. But then here are these things that people picked out about my challenge and I'm feeling vulnerable but they're being courageous to speak up and say it. And I have the same opportunity."
> I think those connections there are other people out there like me in other places that are trying to achieve these same kinds of things and that we can help each other out.

Educators

Purposeful Questions educators were asked to rate the impact of essential elements on their learning using a series of Likert-style questions. The essential elements were compartmentalized into roles played by coaches, peers, and the OST educators themselves. All essential elements received moderate, positive endorsement from OST educators, with average ratings at the upper middle range of the scale (see **Figure 4**). Experiences with their coach (I3), watching peers' videos (S5), and reflections on their practice (I3) were the essential elements that OST educators believed affected their learning most, followed by receiving feedback from peers (S4). Giving feedback to others (S5) and the bond felt with the cohort (S1, S2) were also considered impactful, though slightly less so.

As with those described above, Virtualizing educators were also asked to rate the impact of the program's structure and interactions on their learning. All essential elements were endorsed by Virtualizing educators, with average ratings at the upper end of the scale (see **Figure 5**). Three essential elements were rated using the top options on the scale, with average ratings between 5 and 6. These included the specific roles that the coach played during the instructional PLC (I4), and meeting with the same group over time (S2) to share ideas (I2). Ratings for the importance of reflection activities (I3) and the bonds formed with cohort members (S1, S2) were slightly lower, though these elements were also considered to have a high impact on learning.

Consistent Themes

Each of the structural elements were verified as important by the coaches-in-training, including small cohort size (S1), regular meetings (S2), modeling of skills by a coach (S3, I4), watching and receiving feedback on videos of their own teaching practice (S4, I5), and watching and providing constructive criticism of peers' teaching practice (S5, I5). Though the sample size for the interviews was small, this cohort was convened at a key point in time, when the project team was narrowing its focus on essential elements, and thus provided a meaningful touchpoint for the team. The quotes from coaches-in-training and the essential element highlight the dynamic interplay between structural and interactive components in the program model. The use of videos (I5), for example, sets the stage for the learning that happens through essential elements S4 and S5.

The ratings items used with the Purposeful Questions and Virtualizing Educators attempted to disaggregate these interactions into specific components that spanned a subset of the structural and interactive components of the model. The ratings from both groups of educators verified the importance of these essential elements to learning, with the role of the peer group and coach receiving the highest ratings. Though we attempted to assign items to one or two essential elements for the purpose of this analysis, the integrated nature of the program's delivery may mean that we have under-interpreted these data. The item *receiving feedback from peers about videos of myself*, for example, is likely the combination of several essential elements including the video requirement (I5), the learning environment created by the coach (I1, I2, I3), and the expectation that videos will provide a reflection point for the cohort (S4).

When considering these results as part of the team's DBIR process, the team was encouraged after seeing the essential elements all receiving moderate to high ratings of value. In particular, the item "reflecting on my own practice" was rated very highly (almost five by both groups of educators), showing that the educators valued the foundational approach underlying this kind of PLC. The feedback from both educators and directors gave more emphasis than the team expected on building relationships to reduce isolation; as a result the materials were adjusted to give a greater emphasis to this process during the sessions and also during the recruitment. Also, the skill of giving feedback to peers was initially included as one of the educative essential elements, but when the stakeholders gave it less value than expected, the team removed this element from the list.

The iterative DBIR process also led to the development of supports and adaptations based on the needs and desires of particular participants. For example, librarians tended to have far less experience in STEM activities than afterschool educators, so cohorts of mostly librarians were given a more gradual introduction to the ideas of video-recording their own work with youth, starting instead with a video that simply showed the space in which they worked, as a form of skill-building ice-breaker. Also, the early versions of the materials included particular hands-on activities designed to serve as contexts for the educators to practice their skills, but this was changed when the coaches reported that educators tended to fixate on the activity rather than the skill; later versions had the activities reduced to being optional and educators were instead encouraged to apply the target skill in the context of their own curricular materials. This change emphasized practicing the skill, rather than the tendency to practice the activity. Another element that was allowed to vary was whether the group included senior members of the organization itself, or whether it included only staff members with direct contact with youth. Other adaptable elements included logistical characteristics such as time of day for the sessions, and the number of weeks between sessions (few enough to provide continuity, but long enough for the educators to record their work with youth and update their videos). Such adaptations allowed the program to maximize flexibility and support while still adhering to the essential elements described above.

Expectations for Sustainability, Spread, and Shift

Using the DBIR process provided the context for the leadership team to consider whether and how the program's essential elements help foster initial interest and commitment from OST educators and systems, and the ways in which essential elements set the stage for program sustainability, spread, and shift. Characteristics of OST organizations and educators were also used to consider the systemic factors that affected adoption and continued engagement with the program (Century and Cassata, 2014). Here, we present data from across stakeholder groups that highlights the programmatic aspects of the program that set expectations for sustainability, spread, and shift.

Recruiters

Recall that five recruiters were interviewed on two occasions to share their perspectives about those who did and did not pursue the program. Four recruiters (80%) shared examples of conversations with educators and directors related to decreasing isolation across multiple levels of the OST system. Examples within the microsystem shown in **Figure 1** included educators who felt isolated from one another and directors who felt isolated from their educators. Other examples were at the mesosystem level and included state-level coordinators who felt isolated from national-level systems and funders.

Expecting change in disconnected parts of the OST system assumes sustainability of the personal and professional connections made through the program; having a community of colleagues and making connections to other organizations have each been found to support sustainability (Coburn, 2003). The program featured in this case study was designed to fill a gap in many OST systems, by responding to the fact that many educators work in isolated contexts and thus have a need and interest in connecting with others. Framed within the context of the Innovation Implementation Conceptual Framework, the program was designed to respond to isolation as both a characteristic of individual educators and OST organizations (Century and Cassata, 2014). Expectations for combatting this isolation may be particularly salient to those who were recruiting and working with educators from within the same OST system, as exemplified below.

> The accidental impacts can be the most powerful ones and I do highlight those a lot...So I try to talk about people coming together to learn, and to be connected, and stay connected after the learning experience. So I guess when I tell the ACRES story, I say it's STEM facilitation and I also try to mention it's (going to) make your everyday practice better, build that community with people across the state doing the same work as you.

Coburn (2003) says that, in order for a program to be sustainable, program developers must support a variety of users by allowing minor modifications that do not undercut the core principles of the program, while evolving toward conditions for success. In addition, providing support across multiple levels of a system also supports sustainability. These characteristics are exemplified in the recruiting practices used by the program. Though a defining feature of the program is virtual coaching, recruiters found that some OST systems were more comfortable with a hybrid model that included an introductory session in-person and then virtual professional learning thereafter. The Taster Workshops mentioned earlier function as a successful way to bridge this gap virtually; both directors and educators have been introduced to the program through this mechanism and then gone on to foster and participate in the full instructional PLC.

Recruiters have noted that successful recruitment into the program often required building trust across two types of stakeholders. The first was the decision-maker, often a director, who agreed to offer the program as a professional development opportunity to their staff. The second group was the OST educators themselves. The story below exemplifies both a hybrid approach and the minor modifications made to the program's recruitment and delivery to ensure success. As is often the case, the program recruiter was also the coach for this cohort, ensuring that the initial trust- and relationship-building in the recruitment phase also carried over directly to the instructional PLC.

> For the National Afterschool Association conference I did (an in-person) session on how to reach out to rural educators. A brand-new [statewide] afterschool STEM facilitator stayed afterward and she said, "This is absolutely perfect. This is what I need to help reach out to (my state). Can we work on this? What do we do?" So, (we) talked from March to July, once a month she had me apply to come out to the (state) AfterSchool Conference. I was going to do an in-person session and then we were going to do two actual coaching sessions. What she told me the day of was that everyone was very nervous, that they weren't really sure what they were getting into, and that they were likely not to come if this was the start. I said, "Well, how about we just have it be the intro, just come and learn about it and we can have this group start afterward?" So, I spent that time answering their questions, getting them excited. We did start a cohort. They all showed up.

Spread is defined as dissemination both within and across organizations, which in turn influences policy and decision-making. Spread is another key concept necessary for programs to scale up. Within the context of program recruitment, spread typically occurs through an expanding network of those who have been part of prior cohorts. In later years of the project, the program has also relied on the video testimonials from past participants. This strategy prompted implementation of the program innovation by demonstrating what is possible from the perspective of others who share the same OST context. The potential for spread is also exemplified through the following series of connections, which the recruiter referred to as "relays."

> I think I always have to build the relationship with the first person that I'm connecting to. Because if it's a relay I want to honor that person. (I have one alum) who just happens to have the gift of gab, and gets everybody loving him, and he's memorable. And then he has been relaying people to me (Working with librarians in one state) really happened first that way...He introduced (me to someone in a new state). (That person) was able to pull together a cohort of five, including herself...I feel like in some ways she came out of her Purposeful Questions cohort realizing this benefit and that she couldn't do it all. So that's when she relayed me to the state person...the top leadership position as a state librarian (and) she knew the mechanism to reach more librarians.

TABLE 4 | ACRES pedagogy and strategy implementation, by purposeful questions educators.

	Never	Rarely	Sometimes	Often	Very often
Pre-plan questions	1	7	9	23	19
Open-ended questions	1	3	12	18	21
Wait time	1	6	12	22	16
Facilitate STEM discussion	1	8	13	23	14
Broadening and deepening questions	2	4	19	14	24

Directors

While the examples above demonstrate the potential for sustainability and spread at the mesosystem level, the data from OST network directors demonstrate the features of the program that support these concepts at the microsystem level. For example, directors mentioned various aspects of the learning environment that make it easy for OST educators to participate in the program, and to implement it with youth—both of which allow for program sustainability. The flexibility of the program, which teaches skills that can be immediately applied in a variety of OST settings (n = 4, 67%), and the flexible nature of OST environments (n = 3, 50%) set the stage for the program to be sustained. Indeed, the immediate application of the program is embedded in the essential elements, which encourage OST educators to not only use the program's facilitation strategies, but to video record their practice and bring it back to the group to promote additional learning and reflection (S4, S5). Directors' reflections about the immediate potential for applying the program's facilitation strategies across learning activities included the following:

> The thing that I think is important to say is that of course afterschool programs really require flexibility. They also sometimes really benefit from proposals and models, so you could say, "It could be used this way. It could be used that way, whatever works best for you" But hearing that and having them say, "Okay, I'm not having to invent a whole new way of being. Instead, I'm going to find a way to make this work in scaffold or whatever." That's useful.
> There's flexibility (in out of school programs), and especially on the level of they're already working with a STEM enrichment program, it really is a lot easier, I think, to layer (ACRES) into their practice.

Other aspects that support sustainability are the virtual aspect of the instructional PLC, which eliminates travel time and expense (n = 5, 83%), and the fact that the program is offered at no cost (n = 2, 33%).

> (I saw) an opportunity with ACRES to actually expand our toolbox and work with people virtually, which was a big part of what we were looking for in particular, that would be a huge help to us to reach the state. Most of our state is rural. There's lots of people who want professional development and we can't offer it to them because we can't get there.

Network directors are key to ensuring that information about new professional development programs is communicated to educators and administrators, thus promoting spread to both the OST meso- and microsystems. Most network directors met a leadership team member and learned about the program at an annual national conference or meeting (n = 5, 83%), events that help to maintain the community through which the program spreads. For various reasons, all directors (n = 6, 100%) were excited to share information about the program with their network organizations.

> (This program is) quite attractive and brilliant to think of helping improve your practice by really looking at your practice, and having it be virtual in an age when it wasn't as easy to do as it is right now and today.
> It was the first time I'd heard about a resource like this and then met someone who I knew would understand the role of my group.

Spread can be easier when there are many OST organizations concentrated in a particular area, such as in urban settings, and more difficult to achieve in areas where there are few OST organizations, and where educators often feel isolated. Because it is a virtual program, educators serving in rural areas can participate as easily as educators in urban settings. Spreading to less populous regions is one of the components that network directors found attractive (n = 2, 33%).

> Most of our state is rural. There's lots of people who want professional development and we can't offer it to them because we can't get there.
> It fit well inside of our equity lens, as opposed to having in-person trainings that really force folks from rural communities or smaller communities to not be able to participate.

Shift, a third concept that is necessary to achieve scale, takes place when ownership is assumed by users and is adapted as necessary to fit the unique needs of the organization (Coburn, 2003). While STEM programming can feel intimidating for some OST staff, and staff often want to be taught an activity that they can turn around and immediately teach to youth, the focus is on the *facilitation* of STEM activities. Network directors noted that this essential element (S3) fostered a shift in focus that helped educators become comfortable and confident delivering both STEM and non-STEM programming to youth (n = 5, 83%), thus also creating a change in how educators interacted with youth.

> ACRES wasn't teaching them, "I can do National Youth Science Day and talk about coding." That's not what it's about. It's like, I have a coding project or I want to do a coding activity with my volunteers or teach my

> volunteers, and I don't need to know how to code. I just need to know how to facilitate.
>
> I think a lot of staff are looking for actual activities. "Give me an activity, so I can take it back and use it," which is not what ACRES is about. I think it's more of a mindset that hopefully they walk away with.

Directors shared that another type of change occurred for Purposeful Questions educators. They stated that educators were initially hesitant to participate in a virtual professional development program (n = 5, 83%), because they were either uncomfortable with the technology or because they were concerned about the effectiveness of online professional development. Directors also noted that educators quickly overcame their hesitancy and learned to interact online in a productive and constructive manner, reiterating the success of essential element I5. This new comfort became particularly useful with the onset of the pandemic, as OST educators were forced to shift to virtual models for engaging youth (and not just for their own professional development).

> We got comfortable using virtual tools to do hands-on STEM with people and with STEM itself at the same time.
>
> I think this idea of being online and receiving coaching and feedback and training via Zoom or other platforms. I think folks are really comfortable with it now, so I think that's going to be a real plus.

Educator Evidence of Sustainability, Spread, and Shift

Though a young and growing program, evaluation results do offer early evidence of sustainability. Overwhelmingly, educators have applied the program's facilitation strategies to their work with youth, both in the short and long term. Just after completing the Purposeful Questions module, for example, educators were asked how often they implemented five specific facilitation strategies with youth (see **Table 4**). A total of 98% reported that they had implemented at least one strategy. On average, educators reported that they used one or more of these strategies between *sometimes* and *often* (n = 55–63 across five items, mean = 2.86).

Similarly, Virtualizing educators reported immediate changes in the ways in which they engage with youth. All Virtualizing educators (n = 93, 100%) reported that their participation would impact the youth that they work with. The majority also noted that they had already tried new activities with youth by the end of the program (n = 62, 73%), or shared specific plans for how they will use what they learned with youth (an additional n = 6, 8%).

Months after their professional learning experience, Purposeful Questions educators shared ways that they had sustained their use of program facilitation practices. Most noted changes to how and when they asked questions of their students (n = 15, 79%), the use of open-ended questions (n = 6, 32%), the time they waited to allow students to answer (n = 4, 21%), and the ways in which they posed follow-up questions to students (n = 3, 16%). These longer-term teaching practices are particularly important given that youth outcomes are stronger when they experience high-quality programs that include these kinds of facilitation practices (Allen et al., 2017).

> Letting there be unanswered questions and letting kids come up with questions. And I feel like even outside of STEM, it's been really great to see in everyday life kids doing that work of questioning and wondering, and me not giving them the answer right away.
>
> We did a bridge building program. And I remember asking, "Well, why do you think this type of bridge works?" (for) an existing bridge, Golden Gate Bridge. And then when they were building their own bridge things didn't work. I remember asking them, "Well, why is it not? What made you think of that idea? Why did you think it would work? Why do you think it didn't work?" And I think before ACRES, I might have just been like, "Why didn't it work?" I think I would stop there.
>
> I learned that it's very culturally appropriate to, if you're going to ask a question, to give that long space for both youth and adults to answer. And that was something I was not great at, and I'm still improving upon. But was really a valuable part of ACRES.

Purposeful Questions educators who participated in the longer-term follow-up interviews also reflected on the aspects of the program that supported its sustainability in their practice, as well as perspectives related to spread and shift of their teaching practice over time. The informal nature of OST settings, such as afterschool programs and libraries, marries well with the program's flexibility. Purposeful Questions educators believed that having the freedom to utilize the program's facilitation skills broadly—both for STEM activities and non-STEM activities (n = 17, 94%)—and the flexible nature of OST settings were two of the main reasons they were able to easily adapt, implement, and sustain their use of program pedagogy (n = 6, 33%). As noted above, the deliberate focus on facilitation skills that can be applied broadly (S3), rather than specific STEM activities, also helps support sustainability and spread.

> The afterschool setting definitely helps with ACRES because I felt like I was able to apply the purposeful questions. And if I needed to pivot or kind of change my lesson direction, I had the freedom to do so.
>
> I feel like it's useful in any area...it's education related—it's not just STEM.

In order to sustain change, educators must have support at multiple levels, including a community of colleagues (Coburn, 2003). Fifteen of the Purposeful Questions educators from the follow-up interview stated that they knew none or few people in their cohort before beginning the program (88%). This gave them the opportunity to make connections with educators from other OST organizations, and further expand their community of colleagues. Several essential elements of the program (S5, I2, I3) were designed to help foster these connections. Purposeful

Questions educators noted that the cohort aspect of the program was unique (n = 7, 41%), indicating that they had not had the opportunity to participate in other professional learning communities. Some also shared that they had sustained relationships that were formed during the instructional PLC (n = 4, 21%), providing a long-lasting community of colleagues.

> I remember that I really liked having other people to talk to about it. Like when we were in the online sessions, there were, I think three or four other people to talk to who were also professionals who were taking the same course. So, whereas a lot of professional development, I feel like you're doing alone when you're online. Instead, it was still that group setting. So I really liked that.
> We did talk a lot about (the program) while we were doing it, and even we've referenced it after when we were working on different curricula.

Both the short-term survey results and the longer-term interviews provided evidence that educators were fostering the spread of the program. Just after completing the module, both Purposeful Questions and Virtualizing educators reported being very likely to recommend the program to a friend or colleague (n = 131, mean = 8.85 out of 10 and n = 95, mean = 9.09 out of 10, respectively). During the follow-up interview, 11 Purposeful Questions educators confirmed that they had spread the word about the program by recommending it to a colleague (74%) and sharing stories of their positive experiences (58%).

> I talked to the use services person and kind of to everyone who was working with me at the time, I was very excited about it, and really thought it was something that would benefit librarians in general.
>
> (I) was sort of telling people I think this would be useful for you because it would give you more of a structure for planning your programs and evaluating them and really helping kids to build better problem-solving skills and the things that are at the heart of STEM.

Recall that the concept of shift takes place when ownership is assumed by users and is adapted as necessary to fit the unique needs of the organization (Coburn, 2003). As noted in the section above, Purposeful Questions educators overwhelmingly felt that they could apply the program's facilitation skills broadly (n = 17, 94%). This same freedom also allows for a shift in internal decision making, a key component of scaling up.

> It's good for (STEM), but you can use it everywhere. So I think from that, I felt empowered to think about the same kinds of things for any sort of program I was doing.
>
> We're pretty free to do kind of whatever we want with the kids .we throw art and other things in, but I feel like all of that stuff is related too, you know? You can't just use things that you learn just for STEM. I'm putting it and using it in other places as well. And when we do our planning, it definitely shows. We're, you know, planning more time or being more thoughtful.

DISCUSSION

This study provides an example of how DBIR can be applied to a moderate-sized OST project over the course of a few years to support both program development and to provide initial evidence of the potential for project scale-up. This study responds to a call for examples of research that incorporate considerations of implementation and sustainability early in a program's development (Penuel and Fishman, 2012). A particular focus of this project was to address two persistent problems in the OST STEM sector: how afterschool and library educators can meet the demand for high-quality STEM programming for youth, and how they can engage in professional learning in a culture of social support and reflection rather than reactivity and isolation. To answer these questions, data were collected from multiple stakeholders, using both interviews and surveys, to narrow down and then continue to verify the importance of the program's essential elements. Stakeholder feedback was collected from those who represented different levels of the OST system (e.g., recruiters, directors, educators) and based on multiple types of OST programs (e.g., 21st Century sites, 4H, Boys and Girls Clubs, libraries, and statewide afterschool networks). The team used the data to consider the extent to which the program functioned as expected across OST settings, and to improve the program's design in an effort to increase the program's spread throughout an entire system or organization. This process occurred over a three-year period, and through many iterations and conversations about whether specific essential elements were fundamental to the success of the program or simply characteristics that could be encouraged, but not required. While the focus on essential elements felt overly conceptual and academic at times, being able to verify the essential elements with educators was critically important to considerations related to scale-up, particularly as recruiters continue to negotiate the parameters of new courses with organizational leaders of larger groups.

Regular monitoring of the survey data throughout the implementation provided the project team with the opportunity for continued reflection about the essential elements in practice. The amount of data available and the consistent results related to the essential elements between spring 2019 and spring 2020 supported the team's choices in how to respond to the COVID-19 pandemic. The Virtualizing STEM module itself serves as one example of sustainability for the program, as it demonstrated that the program had a robust design that enabled it to adapt to the changes caused by the pandemic. Importantly, the quality of the professional learning experience, as indicated by educator ratings, indicates that the program did not abandon the essential elements in the process (Dede et al., 2007). One essential element that had to be adjusted under the new pandemic constraints was S4, in which educators make videos of their own practice to share with their instructional PLC cohort. With the majority of such programs going virtual or shutting down, educators were encouraged to be creative: bringing recordings of their zoom sessions with youth, videos of themselves doing STEM activities with their own children, or even lesson plans for their future STEM activities. In this way, essential element S4 became “For a minimum of two sessions, the educators are encouraged to bring videos or other artifacts of their own practice to share with their cohort.”

This study also used the concepts of sustainability, spread, and shift to demonstrate how the project has considered its feasibility for implementation at scale. Sustainability may be the most important of these at this stage in the program’s development, as demonstrating the program’s ability to affect practice in the longer-term is vital if it is to scale-up. The results in this study demonstrate that the program’s design was effective at fostering use of the program’s pedagogical strategies in the short-term, with the majority of educators confirming that they applied specific strategies to their practice while completing the professional learning. Those who were interviewed over six months later also confirmed that they continued to use the program’s pedagogical strategies in their work with youth. The concept of shift was also demonstrated by these educators, many of whom had used the facilitation skills within the context of STEM activities, as expected, and with activities beyond STEM as well.

A number of design characteristics supported the sustainability, spread, and shift of the program. Focusing on facilitation skills that can transfer easily across OST activities is one such example. This feature of the program may be particularly useful in avoiding the replica trap—trying to create carbon copies of programs, without taking local context into account (Wiske and Perkins, 2005)—related to program scale-up. Directors also noted that the program model allowed for slight variation in its implementation, and that this flexibility was an important consideration for OST systems in particular. Another is that the program was designed to create professional learning communities, providing a cohort of colleagues who supported one another during, and in some cases long after, their instructional PLC experience. Many OST educators are isolated in their work. Both the cohort model and the virtual delivery helped to combat this isolation, while also providing the potential for spread and shift. OST directors, in particular, noted the importance of this combination in their decision to offer the program to their educators. The quotes from coaches-in-training and educators affirm the importance of learning and reflecting on their facilitation skills as part of a cohort. Finally, the recruiters took advantage of existing relationships with people in relatively stable organizational positions (e.g., using a “relay” model to recruit their target audience), thereby revealing and leveraging the importance of word-of-mouth recommendations in these populations.

The combined presentation of results related to sustainability, spread, and shift in this paper was made in an attempt to be conservative in framing our results. While each concept has a distinct definition, each construct is also related to and sometimes overlaps the others (Coburn, 2003). In addition, the data used in this study to provide evidence of these concepts were not collected via methods that were designed to measure these constructs specifically; rather, the project team and external evaluator were driven to assess impacts with multiple stakeholders and to iterate the program for effectiveness and adaptability. What was learned, even with modest investment in studies and over a relatively short time period, led to the project being positioned to respond to a pandemic while retaining the elements that had shown long-term impacts.

We have attempted to use the data in this study to demonstrate how DBIR approaches can benefit projects that do not have the ability to do a large-scale study. Even so, the sample size for this study is a limitation of the work. Interview data were collected on a “just in time” basis, depending on the needs of the project team. The data collected in each instance included most or all stakeholders who were available to share their perspectives at that time, and so in that way the sample was comprehensive. Even so, the number of stakeholders interviewed at each time point remained small. In the case of the coaches-in-training and the essential elements, the interview data were used to inform the development of survey items that were then used to collect data from a larger sample. This verification process helps alleviate possible concerns regarding sample size in relation to these topics.

The results presented in this study offer a snapshot in time that is part of an ongoing development process. The team continues to collect and use survey data to explore consistencies and differences in ratings based on group characteristics, and the extent to which educators participate fully in the program. Additional interviews are also planned with educators trained in 2020, to continue gathering evidence of sustainability. This study differs from other DBIR examples in the literature in that it does not include results from the youth who are the final beneficiaries of the program. Existing models, such as the scalability index for technology innovations, include student data as a key factor in determining a program’s readiness for scale (Clarke et al., 2006). By contrast, professional development programs for OST provide unique challenges in relation to this criterion, in that the youth who participate in OST are a notoriously transient group of participants when compared to students in classrooms, and there are no easy equivalents of grades or test scores in an environment designed to nurture emergent, interest-based STEM learning (Friedman, 2008; National Research Council, 2009). Existing scholarship has demonstrated that the kinds of skills fostered by the program improve teacher practices and student achievement (Sailors and Price, 2010; Allen et al., 2011; Campbell and Malkus, 2011). A next step in studying the program will be to attempt to replicate these kinds of results in OST settings.

Even without direct input from youth, we believe that this case study offers a solid example of how DBIR can be utilized to help support program development and to study the scale-up potential of OST programs. We also believe that some of the strategies used in this program can be adopted by others who wish to train educators to combat some of the systemic challenges of OST settings. The project team learned over time, for example, that the instructional PLC approach was of equal interest to library staff and afterschool providers, and that these educators worked well with mixed groups that included those from both OST settings. The program worked better when it was made modular, because a complete course of eight skills over many months was too difficult for most OST educators to commit to or schedule far in advance. Modularity also made it possible for educators to choose the content that was most relevant to their interests and needs.

CONCLUSION AND NEXT STEPS

Enacting online, instructional PLCs that focus on facilitation skills that can transfer across discipline holds particular promise for the field. This type of professional learning helps combat the isolation experienced by many OST educators and provides teaching practices that can be utilized across a wide range of OST activities to support youth development. Some of the modifications to the program over time, such as the primer ice-breaker activity that eases educators into virtual learning and the teaser sessions to demonstrate the program's structure and establish initial levels of trust and comfort, are also strategies that might be applied by a broad range of professional development programs that are exploring online program delivery.

To date, research and evaluation efforts on the ACRES program have focused at the mesosystem and microsystem levels of the learning ecosystem. Targeting these levels is a direct match for the intervention itself, which is enacted with educators. As with many PD programs, data have been collected before and after the training. It is less common to gather follow-up data on perceived impacts, though the results in this paper share promising results. What is missing currently from this study, and from others in the field, is a detailed account of the supports and constraints that educators experience when enacting the program with youth, and the ways that local context interacts with those supports and constraints to create a range of learning environments. It is our hope the work we have shared here provides inspiration for others to join us as we continue to use the DBIR approach to explore the use of PLCs in OST.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

KP, JRE, and SA had primary writing responsibilities for the manuscript. KP and JR also had primary responsibility for collecting a subset of the data used for this study. SA is the principal investigator for this project and thus helped lead the DBIR process described. SB, BN, and KK had primary responsibility for collecting a subset of the data used for this study, and for contributing to how those data were used in the DBIR process.

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Formal Learning in Informal Settings—Increased Physics Content Knowledge After a Science Centre Visit

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Over the past 50 years, the prevalence of interactives in museums and science centres has increased dramatically, with interactive learning proliferating around the world. With a current estimated visitation of 300 million people each year, free-choice learning through museums and related venues has become a major source of human learning over the course of a lifetime. While many studies of visitor experience have examined positive changes in affective components of learning, fewer have examined whether specific scientific content knowledge is included in what is learnt. This research investigated gains in content knowledge through informal science learning. Three surveys were conducted at the Otago Museum's science centre (Dunedin, New Zealand) with visitors eight years and older. The main component of the survey included a brief "formal" content knowledge assessment in the form of a pre-post multiple-choice test, with a focus on physics concepts illustrated in the science centre. Self-reported examples of science learned during the visit and selected items from the Modes of Learning Inventory complement the data. In the pre-post test, prior knowledge was age and gender dependent, with younger visitors and females getting significantly lower scores. Notwithstanding, visitors to the science centre had an overall average of 13% more correct answers in the test after visiting, independent of age and gender. A learning flow diagram was created to visualise learning in the presence or absence of interactivity. As expected, interactivity was found to increase learning.

Keywords: scientific literacy, formal assessment, multiple-choice test, scientific knowledge, science centre, content knowledge

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INTRODUCTION

Science Learning at Science Centres

Learning is one of the most sought-after visitor-related outcomes by museums, second only to revenue (Jacobsen, 2016). This research studied learning in a science centre embedded within a museum.

Stemming from the still discussed deficit model, where knowledge flows from experts to novices (Cortassa, 2016), learning has been traditionally defined in terms of knowledge acquisition (Illeris, 2018). However, it is not knowledge alone what will determine what people will do with information, but their personal values, beliefs and attitudes (Kahan et al., 2012; Cortassa, 2016).

Instead of the deficit model, we have used the Koru Model of Science Communication (Longnecker, 2016) in which informal education is part of a learning ecosystem where facts are transformed into coherent information that can, in turn, be transformed into knowledge when individuals engage with it. Accordingly, we consider science learning to be the structured updating of scientific literacy based on processing new information that challenges a prior state, as described by Barron et al. (2015). In turn, while scientific literacy is a contested construct (Linder et al., 2010), it can be considered to encompass multiple concepts such as attitudes, understanding of the scientific method and engagement with science-related issues (Organisation for Economic Cooperation and Development, 2016). A broad approach to the study of science learning can be found in Solis (2020).

Although not the only component, scientific knowledge is commonly placed at the core of what scientific literacy implies (National Academies of Sciences Engineering and Medicine, 2016). While personal values, beliefs and attitudes need to be considered when speaking of learning, knowledge needs to be considered as well.

This study focuses specifically on learning related to content knowledge, defined as the "knowledge of facts, concepts, ideas, and theories about the natural world that science has established" (Organisation for Economic Cooperation and Development, 2016). Though limited in scope, content and procedural knowledge are reasonable indicators of science knowledge (National Academies of Sciences Engineering and Medicine, 2016). Thus, only for the purposes of this research, science learning is operationalized this time as a change in visitor's scientific content knowledge before and after visiting the science centre.

Value of Formal Assessment

Free-choice learning refers to learning that is up to the individual (Jacobsen, 2016). Many studies have shown evidence of increasing scientific knowledge at science centres (e.g., National Research Council, 2009; Martin et al., 2016), with some estimates stating that informal learning makes up as much as 70–90% of a person's learning (Latchem, 2014) However, assessment in informal environments has typically relied on self-reporting (National Research Council, 2009). Employing self-reporting techniques to assess learning of content knowledge has advantages, but it assumes that an honest respondent is enough for an accurate self-report (Paulhus and Vazire, 2007), and this may not always be so. The "familiarity hypothesis" considers that an individual's familiarity with a science topic is a good reflection of their actual factual science knowledge[1] (Ladwig et al., 2012). However, respondent's confidence is based on the ease with which potential answers come to mind, making people genuinely believe their knowledge or understanding is correct if they feel familiar with it, irrespective of whether it is actually right (Mbewe et al., 2010; Wang et al., 2016).

[1]It also considers that this familiarity is positively correlated with science support, but this is beyond the scope of this research.

Using formal testing to measure knowledge in informal settings can detract from the visitor experience and some researchers consider it inappropriate (e.g. National Research Council, 2009; Fenichel and Schweingruber, 2010). Nonetheless, self-reports are biased by personal judgements; assessing content knowledge objectively can be a valuable complement to self-reports and indirect measures.

We conducted an exhaustive literature review for articles, books and reports where formal content knowledge was assessed in informal environments. In total, only six manuscripts included results of knowledge being objectively tested when related to learning experiences in an informal environment (e.g. Mbewe et al., 2010; Salmi et al., 2015; Martin et al., 2016). A discussion of these studies can be found in Solis (2020). While some of those studies conducted a test in the pre-post manner we did, they tended to focus on school students, and none of them was conducted on a wider range of visitors to science centres.

This research included formal testing of scientific knowledge with visitors to a science centre; the drawbacks of such an assessment were considered, the risk of alienation was taken seriously, and the research test was designed to be user-friendly and minimize alienation.

The Otago Museum's Science Centre

The Otago Museum is located in the city of Dunedin and it is named after the Otago Region in the South Island of New Zealand. The importance of this museum to the community is reflected in it regularly having more than 350,000 annual visitors (Otago Museum, 2018), a substantial proportion who are local residents.

This study was conducted at the Otago Museum's science centre in two steps. Piloting happened in early 2017 at Discovery World, the museum's science centre before it underwent a major redevelopment. Surveys were conducted in 2018 at Tūhura, the redeveloped and renamed science centre. The area dedicated to science exhibits increased from 393 sq. m. in Discovery World to 654 sq. m. in Tūhura, with both including a warm and humid enclosure called the Tropical Forest (215 sq. m.). The Tropical Forest is full of greenery and butterflies fly freely throughout. The science centre is a favourite of small children, with one third of Tūhura visitors being under 7 years old (**Table 3**). Tūhura is also popular with adults, some of whom visit without children. For example, the Museum runs occasional "after-dark" sessions without children and these usually sell out.

METHODS

Instruments

Approach

This study triangulated measurement of informal science learning using three approaches: objective testing of scientific content knowledge, self-reporting of learning, and open questions which asked for specific examples of learning. A survey was piloted in 2017 and then three surveys were conducted in 2018, administered by the first author, using the same surveying

TABLE 1 | Questions and answers to assess scientific knowledge.

Tūhura	Discovery World	Question	Options[a]
Tūhura	Discovery World	1. Can you see electromagnetic waves?	I can see some of them Yes, all of them No, none of them
Tūhura	Discovery World	2. Can atoms give off light?	Yes, they can No, they can't Yes, but only in labs
Tūhura	Discovery World	3[b]. What can be used to split white light into different colours?	Prism Mirror Camera
Tūhura		4. What colours can you combine to form white?	Red + Green + Blue Cyan + Yellow + Magenta Red + Blue + Yellow
Tūhura		5. Does your body give off infrared radiation?	Yes, all the time No, never Yes, but only sometimes
Tūhura		6[c]. Which of the following things is necessary for an aurora to happen?	An atmosphere Must be wintertime No moon in the sky

[a]"I don't know" was an optional answer for each question. Questions and their correct answers are greyed out.
[b]Control question in Discovery World.
[c]Control question in Tūhura. The museum has a planetarium and one of the five shows had a short mention of auroras. However, only one in five of the visitors reported going to the planetarium. Since the particular show was not popular, it is expected that very few visitors had access to that information.

methodology for all. Surveys were created and hosted in SurveyGizmo™. The study was approved by the Human Research Ethics Committee at the University of Otago (17/062). The sections of the surveys that provided data analysed in this manuscript are attached as **Supplementary Material**.

Formal Assessment Questionnaire

The research instrument comprised five multiple-choice questions focused on light and electromagnetism, key topics showcased in Tūhura, plus a control question that was not included in the exhibits (**Table 1**). Multiple-choice questionnaires can be used to assess content knowledge (Brady, 2005; Kahan et al., 2012). All the items had one answer that was right, two that were wrong, and an extra "I don't know". The questionnaire was created by the authors and was iteratively reviewed by a panel of experts in science communication.

The score of scientific content knowledge in light and electromagnetism was calculated as the sum of right answers (1 for each right answer, 0 for incorrect answers, not including the control question). "Don't know" options were counted as incorrect, (Salmi et al., 2015).

A short two-item test (plus a control question) was piloted in 2017 at Discovery World. The number of right answers increased significantly (Wilcoxon Signed Rank Test, $Z = 5.816$, $p < 0.001$, $r = 0.389$, 89 discordant pairs of 224) from a median of 0 before the visit to 1 (out of 2) after the visit.

Given the formal nature of this instrument in an informal setting, alienation could be a concern. To minimize alienation, a number of approaches were taken: 1) Questions were selected such that the risk of conflict between the questions and visitor worldviews were minimal[2], 2) The survey was as short as possible, 3) The person administering the survey welcomed visitors and was friendly and respectful when asking for participation, responding to all questions from parents and children, 4) Respondents were given enough space to fill out the survey without feeling observed or pressured, 5) Places to sit were provided), 6) iPads were used to survey (**Section 2.2.3**), 7) A token was given to respondents on completion, as a sign of appreciation (**Section 2.2.4**).

There were few signs of bias (e.g. children feeling everything is five stars) or visitor alienation (e.g. skipping questions in the survey), giving confidence to add more questions to a final five-item (plus control) questionnaire that was then conducted in 2018 at Tūhura. The questions from the pilot were included in the final version of the test. The control question in the pilot became an actual question in the final version of the test, as its topic was not covered in an exhibit in Discovery World, but it was in Tūhura. A new control question was added to the final version. This questionnaire (**Table 1**) was asked in what hereafter is called

[2]An example of alienating question for some people would be "Is Earth flat?"

TABLE 2 | Items from the Modes of Learning Inventory (MOLI)[a] used in this research.

MOLI1. I discovered things that I didn't know
MOLI2. I learnt more about things I already knew
MOLI3. I remembered things I hadn't thought of for a while
MOLI4. I shared some of my knowledge with other people
MOLI5. I found the exhibition educational
MOLI6. I got curious about finding out more about some things

[a]From Griffin et al. (2005).

Survey A. Although all items were related to light and electromagnetism, they cover multiple subtopics and it cannot be expected that someone who learns about one, knows about the others. In other words, the multiple-choice test is not a scale and scientific knowledge is not necessarily mathematically unidimensional, nor a concrete construct. The Kuder-Richardson Formula 20 (KR-20) coefficient (equivalent to Cronbach's alpha for dichotomous values, such as right/wrong) was 0.506 before and 0.542 after the visit.

Modes of Learning Inventory (Selected Items)

The scientific content knowledge test is able to quantify learning, but does not capture non-content learning, or content learning outside the specific questions asked. To provide a measure of whether visitors themselves believe they have learned and how they learned, Environmetrics Pty Ltd. created the Modes of Learning Inventory (MOLI), a 10-item, five-point, Likert-type scale developed by Griffin et al. (2005). MOLI was designed to be conducted only once, after a visit. For the present research, reversed items and those considered complicated for children were dropped. The remaining six items (**Table 2**) were included in the after-the-visit Survey B. As expected, the subset was still unidimensional[3]

Direct Self-Report

Since cognitive changes are highly individual and difficult to assess in a standardized way, outcomes need to be assessed in a variety of ways (National Research Council, 2009). Individuals are capable of understanding and self-reporting their own learning[4] (National Research Council, 2009; Falk and Needham, 2013; Colliver and Fleer, 2016). Directly asking a visitor if they learnt something new is one way to assess changed knowledge and understanding (Longnecker et al., 2014). In Survey C, visitors were asked "Do you consider you learnt something at Tūhura's exhibits that you did not know before? (including any previous visits)" (Yes/No/I haven't interacted with Tūhura's exhibits). In total, 276 said Yes and 78 said No[5]. Those who said Yes were asked "Can you give an example of something you learnt?". Examples were given by 196 respondents. In addition, "It was cool learning about . . . " was an open question included in Survey A, answered by 394 participants. Qualitative responses from both surveys are provided as examples of learning.

Variables Involved in Learning

To combat the view of some young people that science is boring (Linder et al., 2010), the first generation of interactive museums started in 1969 with the Exploratorium in San Francisco and the Ontario Science Centre in Canada (Patiño, 2013). Since then, interactivity has been expected to be a key variable in learning science at a science centre, as interactive elements are more attractive to visitors (McKenna-Cress and Kamien, 2013), promote learning (Fenichel and Schweingruber, 2010), and make the experience more memorable (Maxwell and Evans, 2002).

It is important to define what is meant here by interactivity. Hands-on interactives are those where the user interacts with their hands, but interactivity is a much broader concept, as broad as the ways a visitor can influence an exhibit's functioning. For example, Tūhura showcased an infrared camera. To interact with it, visitors do not need to touch anything. The simple act of standing in front of the camera makes the exhibit change what is displayed on the screen (the temperatures of the visitor's body). However, interactivity does not occur until the user completes the cycle of interaction; in this example, the cycle is complete when the visitor pays attention to what the screen is displaying.

Learning is a complex process that is influenced by a multitude of factors, such as age and gender (Wehmeyer et al., 2011). However, conclusions about the relationship between these variables and learning vary. For example, Ramey-Gassert (1997) concluded that both children and adults learn science at science centres, but Allen (1997) found a very different result. Allen interviewed visitors who interacted with a "coloured shadows" exhibit[6] to see if they provided more correct answers to questions about the nature of those shadows (asked during the interview and later assessed). The success rate in getting the correct answers after an intervention was null for visitors under 12 years old, very small for those between 13 and 15 years old, and only considerable for those 16 and above (Allen, 1997).

Since learning occurs more readily if there is some prior knowledge and the topic resonates with the visitor (Krajcik and Sutherland, 2010; Falk and Dierking, 2016; Mattar, 2018), prior knowledge (operationalized in this research as the score in the pre-knowledge test) was another variable to study. Comparison of results of pre and post answers to survey questions with answers to a control question which asked about information that was not included in the science centre exhibits provides greater confidence that differences observed after the visit were indeed indications of learning. Even if science learning is one of a venue's primary objectives, it is not necessarily on a visitor's free-time radar (Burns and Medvecky,

[3]A single factor explains 50% of the variance (Bartlett's test of sphericity χ^2 (198,15) = 319, $p < 0.001$, KMO = 0.816) the internal consistency was acceptable ($\alpha = 0.784$).

[4]Notice that the need for proving there is knowledge gain objectively does not discredit the supposition of self-reporting validity. To the contrary, a positive gain objectively measured can strengthen the self-reporting assumption.

[5]Also, 17 people skipped the question and 15 people responded that they did not interact with the exhibits. These respondents are not included in the calculation of percentage of visitors learning after interacting with the exhibits.

[6]In this exhibit, lights of different colors shine on the same spot. Objects blocking these lights produce colored shadows. A very similar exhibit is on display at Tūhura.

TABLE 3 | Percentage demographic comparisons of survey respondents, and general visitors visually assessed.

—	N[a]	Gender[b] (%)		Age (%)					
	Total/Gender/Age	F	M	<2	2–7	8–12	13–18	19–40	41+
Survey A	456/452/451	59	41	NA	NA	25	17	34	24
Survey B	198/198/196	59	39	NA	NA	30	19	21	30
Survey C[c]	354/351/349	60	39	NA	NA	26	21	32	20
Visual assessment	3493/3301/3493	56	44	6	26	12	8	30	18

[a]Gender and age sample sizes may be smaller than the total sample size due to missing values. Gender was not assessed in the visual count for visitors less than two years old.
[b]"Other" gender responses were counted, but are not displayed due to very small numbers (≤1%).
[c]Survey C demographics do not include visitors who skipped the question about whether they had learned something at the exhibits, nor those who did not interact with the exhibits.

2016). The three surveys also asked why visitors came to Tūhura (pre-visit) and what they actually did during their visit (post-visit). The option "Interact with the exhibits" appeared in the pre- and post-test surveys to measure how many originally disengaged visitors became engaged with the exhibits. Complementing, but not paired between surveys, "Learn some science" was a pre-visit option and "Read some panels" was a post-visit option. These questions were added to potentially explain other results as complementary factors to interactivity.

Data Collection

Target Population

Visitors of all ages come to Tūhura, but given that survey questions require a certain maturity to be answered correctly, it was decided to limit participants to those over a minimum respondent age. According to the National Research Council (2009), children older than seven years are able to respond to questionnaires, but the age limit for this study was increased to eight years old, as seven to eight is the age when children enter the "concrete operational stage" in Piaget's theory of cognitive development (Piaget, 1968).

We acknowledge that emotional reactivity and regulation are age-related (Silvers et al., 2012), but as mentioned in **Section 2.1.2**, questions were designed to minimize alienation. The format was explicitly designed and tested for being easy for younger respondents while not being patronizing for adults. This allows use of age as a variable in statistical comparison of changes in content knowledge. More detail about development of instruments directed at children as well as adults can be found in Solis (2020).

Pre-test/post-test Design

The MOLI instrument and the open questions do not require a comparison between two points of time and were only asked in the corresponding post-survey. The knowledge questionnaire matched participants' pre-test and post-test responses, allowing true comparison (Friedman, 2008; Hernández et al., 2014) to assess changes in scientific literacy of visitors.

Use of iPads and Visit Time

A strategy used to avoid alienation involved the use of iPads to administer the surveys. The pilot assessed the formal test and compared the use of iPads versus paper. Visitors commented that the use of iPads was "cool" and paper surveys were only kept for emergency (e.g., if internet was down) or visitors who might prefer paper requested one. None of these scenarios happened, all data analyzed in this study were collected on iPad.

Although sometimes younger visitors needed to instruct older relatives on iPad use, the appeal to use iPads in this informal setting was independent of age, gender and group composition. Compared to paper, electronic surveying produces equivalent results in terms of missing data, item means, and internal consistencies (Giduthuri et al., 2014; Ravert et al., 2015), response rates (Ravert et al., 2015; Shah et al., 2016), and time spent completing the survey (Shah et al., 2016). Moreover, using iPads instead of pencil and paper has advantages such as saving time in responding to closed questions (Giduthuri et al., 2014), presenting a more attractive and uncluttered questionnaire (Fowler, 2013), and allowing randomized presentation of items, which increases reliability of the instrument (Fowler, 2013). Lastly, using the iPads allowed visit time to be recorded. However, this information was of limited use, as the time spent at the relevant exhibits could not be separated from time spent in the Tropical Forest.

Non-monetary Incentive

As an incentive for answering a formal questionnaire, a small token was given to respondents as a token of appreciation—a small glow in the dark item or a magnetic butterfly. The token was attached to a piece of paper with a scientific fact and it was given after completing the post-survey.

Sampling and Demographics

All Tūhura visitors were asked to participate in the surveys provided they were at least 8 years old (with consent of the carer), there were at least two iPads available, and there were enough caretakers in a group to look after the youngest children while other members of the group filled out the survey.

Survey A was conducted from May to August 2018, Survey B in September and October 2018, and Survey C from July to September 2018. Piloting at Discovery World happened in June and July 2017.

Table 3 shows respondent demographics. For ease of interpretation, age was divided into groups: Children (8–12 years old), Adolescents (13–18), Young Adults (19–40) and Mature Adults (41+). Visitors came mainly in family groups (75%), their ethnicity was mainly European (87%) and most (78%) agreed to participate. Response rate was calculated by dividing the number of groups that accepted by the number of groups that were asked.

To be able to compare respondent demographics to those of the general visitor population, visitors (respondents and non-respondents) demographics were also visually assessed (**Table 3**). The sampling method affected the group distribution because of exclusion of visitors under seven years old.

Data Pre-processing

Ideally, data should be correct, unambiguous and complete (Kimball and Caserta, 2004), but real world data are often inaccurate and need to be cleaned (pre-processed). For example, data quality can be improved by removing survey responses that exceed an acceptable number of missing attributes (Kimball and Caserta, 2004). A method to detect these invalid responses was devised (for full description, Solis, 2020) and data reported in this paper were cleaned. Respectively, for each survey, the number of drop-outs/invalid responses/valid responses with not enough answers in the instrument/and final number of valid responses with enough answers in the instrument, were as follows. Survey A: 45/26/8/456. Survey B[7]: 18/12/51 (7)/198. Survey C[8]: 24/13/32/354.

To comply with ethics recommendations by the institutions involved, no questions were forced and respondents were allowed to skip any as they so desired. As a result, sample sizes vary for different questions. Of the 198 valid MOLI responses, 23 included up to two missing values (pre and post counted separately), either blanks or I Don't Know[9]. After determining data were missing at random (MAR), missing values were input with Expectation Maximization in SPSS v25. Cronbach's alpha before and after imputation changed minimally from 0.788 to 0.784. The multiple-choice questionnaire does not form a scale and therefore it is not imputable. Blanks and I Don't Know responses were counted as incorrect.

Quotes are shown verbatim, with clarifications signaled in brackets. Respondent gender and age in years are reported in brackets after each quote.

RESULTS AND DISCUSSION

Learning Scientific Content Knowledge

Scientific Content Learning

Scientific content knowledge about light and electromagnetism increased significantly ($N = 456$, t (455) = 11.9, $p < 0.001$) from a mean score of 1.96 correct answers (out of five) before a visit to the Tūhura science centre, to 2.61 after a single visit. Length of visits varied[10] from 8 min to 3 h:31 min with an average stay of 1 h:52 min. The control question added confidence to this result as there was no change in proportion of right or wrong answers after the visit.

The effect size ($d = 0.560$, $d_{CI} = 0.068$)[11] falls in what Hattie (2009) catalogues as the "zone of desired effects learning", i.e., learning surpassed what is expected from formal schooling. Although formal education may produce deeper learning than a one-off visit to a science centre, Hattie's interpretation of Cohen's d reinforces that informal education can be a powerful ally to formal education.

Self-reported Learning

From the questions from the Modes of Learning Inventory (MOLI), 86% (n = 170) of visitors reported their visit resulted in high or very high learning[12]. While only 36% ($n = 128$, $N = 356$) of Tūhura visitors specifically said that they came to the science centre to learn some science in the pre-visit survey, 78% ($n = 276$, $N = 354$) reported in the post-visit survey that they had learned something they didn't know before. Those who responded yes were asked to give an example.

"Plasma the fourth form of matter was something I knew but almost forgot previously" (F, 33). "Recalling torque and inertia was leanring (a learning) event—need to go back to my physics texts of 40 years ago!" (M, 58). Remembering something we have forgotten or strengthening existing knowledge can be considered learning (Falk and Dierking, 2016). These quotes are evidence that formal and informal education can work together to help people learn and consolidate their learning.

The following two responses exemplify that learning is an individual process: "That you can balance an object on the tourqe (torque) board if you get the object to have a matched tourqe (torque)" (F, 19). "That if you spin the ball in the opposite direction that the disc is spinning, it stays on there longer" (F, 52). These two visitors both caught what the Torque Table exhibit[13] was trying to convey. The response of the former appears more conceptual, and she is using the terminology displayed at the panel. The second visitor's explanation is practical and direct, and her learning may have occurred primarily by experimentation rather than reading the panel.

Any doubt of whether children can learn science by visiting a science centre should consider the following self-reported example of learning: "1. I have learned how to make still objects move at the animation station 2. Through an experiment I have learned how humans conduct electricity 3. I learned that white has many different colours" (F, 9).

The effect of the science centre does not stop with learning science content, visitors can develop a sense of inquiry, as can be appreciated from the following quote: "How you could create

[7]In Survey B, the MOLI questions were not included at first and 44 of visitors who left valid responses, filled out the survey without the instrument. Only seven of those who had the complete version and left a valid response, did not have enough answers in the instrument.

[8]In Survey C, valid responses with not enough answers comprise those who skipped the direct question (n = 17) and those who did not interact with the exhibits (n = 15).

[9]Missing values not only come from blanks, but also from I Don't Know responses (Kimball & Caserta, 2004).

[10]These calculations come from all available data of visit time (N = 1,090), all coming from the three surveys, but with no restrictions of other types of data availability (for instance, visit time of those who skipped any of the questions or instruments here discussed are still counted).

[11]d_{CI} is the confidence interval of the reported Cohen's d.

[12]MOLI scores range from 6 to 30. Results were recoded as Very Low (6–10 points), Low (11–15), Medium (16–20), High (21–25) and Very High (26–30). Descriptives were rescaled to values from 1 to 5.

[13]The Torque Table is a turning disc where you can roll objects over the disc to discover how they react to circular motion.

white by using the colours "Red + Blue + Green = White". I wonder if [I] could make white using paints?" (F, 11)[14].

Learning Factors

Age

The selected MOLI items suggest that learning is not age dependent, as no clear age pattern was found (Children, n = 59, Mdn = 3.83, IQR = 0.83, CI = 0.33; Adolescents, n = 37, Mdn = 4.17, IQR = 0.75, CI = 0.17; Young Adults, n = 42, Mdn = 4.00, IQR = 0.71, CI = 0.17; Adults, n = 58, Mdn = 4.17, IQR = 0.67, CI = 0.17). However, the multiple-choice test provided an opportunity for an objective test of the possible correlation. In results consistent with MOLI, the test found learning at Tūhura was not age dependent ($r = 0.023$, $p = 0.622$, $N = 451$).

To further consider how age relates to learning content knowledge, a LOESS fit[15] was done on a scientific content knowledge scatter plot before and after the visit to Tūhura (**Figure 1**) against the independent variable of age. While a LOESS fit does not produce correlation coefficients, it allows us to see two clear sections with roughly linear relationships between scientific content knowledge and age, but with different slopes. The domain of one of the relationships includes Children and Adolescents, while the domain of the other one includes Young Adults and Mature Adults. The independence of age and learning can be visually appreciated in **Figure 1** as shapes from before and after are similar, regardless of the age group, with both shifting upwards after the visit.

In contrast, Allen (1997) found considerable science learning from a science exhibit only in visitors 16 years and older. However, that result may be due to the nature of the exhibit that was studied. In "coloured shadows", how shadows get their colour is counterintuitive and requires a good deal of abstraction—something that does not start to develop until adolescence (Piaget, 1968). Also, prior knowledge is important for learning abstract concepts (Krajcik and Sutherland, 2010).

Prior Knowledge

Figure 1 shows how Tūhura visitors' prior scientific content knowledge in the topic of this study depended on their age in the range from eight to 22 years old[16] (r (237) = 0.440, p < 0.001). From the age of 23 there was no further age-related increase in prior scientific knowledge, (r (214) = 0.005, p = 0.938). This finding agrees with Lindon (1996), in that knowledge is accumulated with age, especially in young people. The ages where knowledge increased rapidly is consistent with the typical age of formal schooling. "From eight to 18 years there is great potential for children and young people to extend their knowledge tremendously (Lindon, 1996). Notwithstanding, the parallel upwards shift of curves from pre to post in **Figure 1** also demonstrates that the influence of informal learning can be important, even when compared to that of traditional schooling, as has been suggested by Falk and Needham (2013). The increase in scores from pre to post-test at all ages demonstrates that adults continue to learn when provided opportunities outside of school.

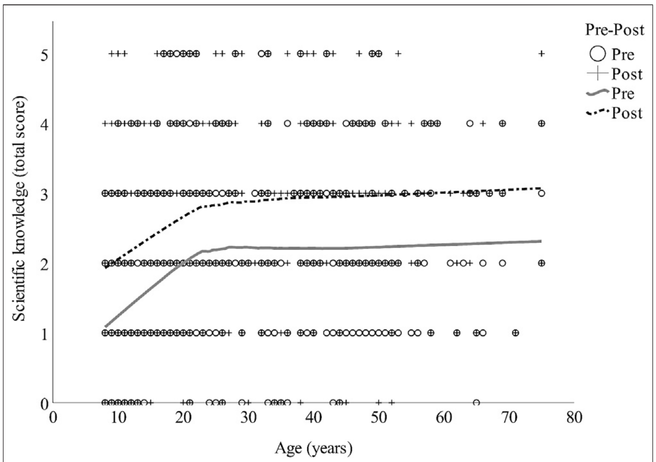

FIGURE 1 | Scatter plot with LOESS regressions (smoothing parameter $\alpha = 0.70$) for scientific content knowledge as a function of age, before and after the visit (N = 451) at Tūhura.

The flatter section (from 23 years old) does not mean adults learn less, but that their priorities may tilt their learning to other subjects (Flynn, 2012), not assessed with this instrument (which only measured the topic of light and electromagnetism). Instead of being generalists, adults tend to develop expertise in specific domains (Fenichel and Schweingruber, 2010).

Gender

The prior scientific knowledge of males (M = 2.23, SD = 1.40, CI = 0.20) was significantly higher (t (345) = 3.69, p < 0.001, $n_m = 185$, $n_f = 267$, d = 0.359, $d_{CI} = 0.096$) than that of females (M = 1.77, SD = 1.15, CI = 0.14). Females scoring lower than males in prior scientific knowledge about physics (**Figure 2**), is consistent with other reports showing a gender gap in scientific literacy unfavourable to females (e.g. Allen, 1997; Skaalvik and Skaalvik, 2004; Kurtz-Costes et al., 2008). A multitude of reasons have been proposed to explain this gap, including low self-esteem in science (Bamberger, 2014), stereotype related issues (Bian et al., 2017) and lack of opportunities (Aikman and Unterhalter, 2007). We agree with the reasons above and discuss another factor.

In **Table 4** it is seen that there is no prior knowledge gap in Children; the gender gap starts from adolescence onwards. This difference does not need to come from some sort of discouragement necessarily. On the one hand, engagement is a

[14]Scientific inquiry is a desired outcome, but it can lead to misinterpretations if not correctly guided. This topic will be covered elsewhere.

[15]A LOESS fit (Locally Estimated Scatterplot Smoothing, a.k.a. LOWESS, Locally Reweighted Scatterplot Smoothing) is similar in nature to a linear regression, but instead of producing a single and linear regression from all data points, it creates multiple weighted local linear regressions around each point by using a subset of n neighbouring points. Although the LOESS fit is merely descriptive and does not produce a correlation coefficient as the linear regression would, it is useful to detect relationships by zones, as it will become clearer below.

[16]The age dependent group was extended beyond Adolescents because the plot and Pearson correlations showed the dependence was still high until 22 years old.

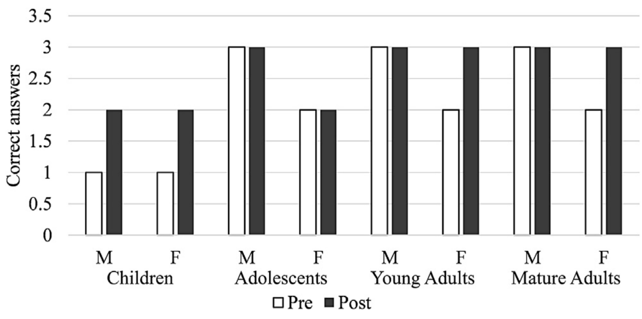

FIGURE 2 | Medians of correct answer before (pre) and after (post) visiting Tūhura for male (M) and female (F) visitors: male children (*n* = 56), female children (*n* = 55), male adolescents (*n* = 21), female adolescents (*n* = 55), male young adults (*n* = 57), female young adults (*n* = 96), male mature adults (*n* = 50) and female mature adults (*n* = 57). Children comprised visitors from 8 to 12 years old, Adolescents from 13 to 18, Young Adults from 19 to 40 and Mature Adults from 41.

cornerstone that supports effective science learning and interest in learning more (Krapp and Prenzel, 2011). On the other hand, career choices are influenced not only by confidence and interest in science, but by relative academic strengths (Stoet and Geary, 2018), and it was found in 2015 PISA that boys had a significantly larger rescaled intra-strength in Science, while girls' intra-strength was in Reading[17] (Stoet and Geary, 2018).

STEM careers can be divided into two broad categories, physical STEM careers and life sciences STEM careers (Mohtar et al., 2019). It is well documented that girls tend to have less interest in physical sciences than boys (Krapp and Prenzel, 2011). More specifically, females tend to be more attracted to biology and males to physics (Akarsu and Kariper, 2013). An important factor for women's underrepresentation in physics may be their own choices that start at a young age (Williams and Ceci, 2012) and that are based on having more areas where they feel they can succeed (Mostafa, 2019). A deeper discussion on the gender gap and the relation between content knowledge and self-concept will be presented elsewhere. Regardless of the gap, it is interesting to note that both genders increased their content knowledge significantly, males going up from M = 2.23 to M = 2.84 (t (184) = 7.13, $p < 0.001$, d = 0.524, n = 185, $d_{CI} = 0.106$) and females from M = 1.77 to M = 2.45 (t (266) = 9.51, $p < 0.001$, d = 0.582, n = 267, $d_{CI} = 0.088$). If we take the pre-post difference in right answers (ΔM) as a measure of content knowledge learning, females ($n_{females} = 259$, ΔM = 0.68, CI = 0.14) are not significantly different (t (423) = 0.180, *p* = 0.857) from males ($n_{males} = 175$, ΔM = 0.66, CI = 0.17). This agrees with Piraksa et al. (2014), who found that gender did not influence scientific reasoning in students in Thailand.

Self-reports are also interesting in this regard. The MOLI responses for males (*n* = 78, Mdn = 4.08, IQR = 0.83, CI = 0.08) and females (*n* = 117, Mdn = 4.00, IQR = 0.83, CI = 0.17) were not statistically different (Mann-Whitney *U* = 4,342, *p* = 0.564, *r* = 0.041), but the percentage of females reporting new learning when asked "Do you consider you learnt something at Tūhura's Exhibits that you did not know before?" (82%, *n* = 213) was significantly higher ($\chi 2$ (1) = 6.37, *p* = 0.012) than that of males (72%, *n* = 138). Due to the small sample size of sub-groups, medians instead of means were used. **Table 4** complements **Figure 2** by showing the results to testing for statistical differences in these subgroups. While adult female visitors increased their test scores more than adult male visitors, no statistical difference was found in children.

Interactivity

Tūhura visitors who interacted with exhibits changed their answers significantly between the pre and post-test surveys (McNemar-Bowker test χ^2(3,n' = 1973) = 166, p_{asym}<0.001, DPRS = 14.0). The non-interacting group did not (χ^2 (3,n' = 127) = 3.628, p_{asym} = 0.305, DRPS = 0.007). **Figure 3** shows this graphically[18]. The amount of answers that changed[19] was the same in both groups (33%). However, those who interacted with the exhibits have a large net flow towards the right answer, while the distribution of those who did not interact is more random.

It is important to acknowledge that interactivity is not a factor that works alone. Engagement with the exhibits translates into more time playing with them, and more time at the exhibits means more opportunities for learning (Serrell, 1997). As expected, visitors who interacted with the exhibits stayed (*n* = 692, t = 67 m 09s, SD = 25 m 02s, CI = 1 m 52 s) significantly longer at Tūhura (t (742) = 3.542, $p < 0.001$, *d* = 0.516, *F* = 0.144) than those who did not interact with the exhibits (*n* = 52, t = 54 m 26 s, SD = 24 m 14 s, CI = 6 m 34 s). Unfortunately, time spent exclusively at the exhibits could not be isolated from the total which could include time spent in the Tropical Forest.

Another indirect factor that could account for the increased learning by those interacting is the possibility that those interacting also read the panels. But the difference in means of right answers from pre to post in panel readers (ΔM = 0.60) and non-readers (ΔM = 0.60) was not significant (t (425) = 0.544, *p* = 0.587, $n_{NR} = 115$, $n_{PR} = 312$, *d* = 0.061, $d_{CI} = 0.109$), meaning that those who did not read the panels were as likely to provide correct answers as those who did. This is predictable to some extent, given the interactive nature of the exhibits, which were designed to be self-explanatory.

[17]PISA assess three main subjects: Science, Reading and Mathematics. While there would not be a gap in Science in absolute terms, boys tend to score higher in Science than in the other two subjects, and girls do so in Reading.

[18]The learning flow diagram was created by the authors to visualize how scientific knowledge learning happens. The way to read it is as follows: circle diameters are proportional to the number of answers that did not change from pre to post. Arrows show how answers moved among the three options. The direction of the arrow explains from what-to-what group answers moved. The width of each arrow is proportional to the number of answers that changed from one group (in pre) to another (in post).

[19]The total percentage of answers that did not change can be obtained by summing up the percentages in the three circles. The total percentage of answers that did change is obtained from summing up percentages of all arrows.

TABLE 4 | Statistical significance of differences of correct answers (medians) in scientific content knowledge before (B) and after (A) the visit by gender and age group in Tūhura.

Children (8–12)	**Males**	**Females**
Pre-post difference	$Z = 4.52$, $p < 0.001$, $dp = 37$, $r = 0.427$, $n = 56$	$Z = 3.52$, $p < 0.001$, $dp = 35$, $r = 0.336$, $n = 55$
Gender difference	Before $U = 1{,}459$, $p = 0.618$, $r = 0.052$, $n = 95$	
	After $U = 1{,}349$, $p = 0.252$, $r = 0.118$, $n = 95$	
Young Adults (19–40)	**Males**	**Females**
Pre-post difference	$Z = 3.43$, $p < 0.001$, $dp = 35$, $r = 0.322$, $n = 57$	$Z = 5.12$, $p < 0.001$, $dp = 58$, $r = 0.370$, $n = 96$
Gender difference	Before $U = 1887$, $p = 0.001$, $r = 0.266$, $n = 153$	
	After $U = 2{,}171$, $p = 0.029$, $r = 0.176$, $n = 153$	
Mature Adults (41+)	**Males**	**Females**
Pre-post difference	$Z = 2.95$, $p = 0.003$, $dp = 30$, $r = 0.295$, $n = 50$	$Z = 4.40$, $p < 0.001$, $dp = 39$, $r = 0.413$, $n = 57$
Gender difference	Before $U = 1{,}013$, $p = 0.008$, $r = 0.257$, $n = 117$	
	After $U = 1{,}219$, $p = 0.184$, $r = 0.129$, $n = 117$	

NB: dp stands for the number of discordant pairs. Adolescents are not included because the number of male Adolescents is too small (n = 21), but the pre-post difference in female Adolescents is significant (Z = 3.73, p < 0.001, dp = 31, r = 0.356, n = 55).

Another possible factor is that visitors who came with the intention of learning science worked hard towards their aim and their increase in science knowledge was so high that it influenced the results of the entire interacting group. However, the amount learned by those who said they came to learn some science ($n = 295$, $\Delta M = 0.64$, CI = 1.14) was not statistically different (t (425) = 0.183, $p = 0.855$, $d = 0.03$, $F = 0.322$) from those who stated no intention to learn science in the pre-visit survey ($n = 132$, $\Delta M = 0.67$, CI = 0.20).

LIMITATIONS AND FUTURE WORK

It is acknowledged that pre-testing may have "cued" (pre-sensitized) visitors (Friedman, 2008), affecting the outcome. However, matching pre and post responses is a widely-used experimental design that allows for changes to be detected in the same population (Friedman, 2008; Hernández et al., 2014). Feedback, worked examples, scaffolding, and elicited explanations play a big role in learning (Honomichl and Chen, 2012). Therefore, an extraneous variable that might have influenced the results of children are parents, as they and others in mentoring roles play a critical role in supporting science learning (Fenichel and Schweingruber, 2010). The role of parents or carers was not determined in this study.

Very little research has been done on formal assessment of content knowledge in informal settings. More research is needed to confirm the results found in this study, especially considering science learning is a much broader concept whose study requires considering other areas.

It would be interesting to investigate whether visit time at specific exhibits is correlated to learning, as has been suggested by Serrell (1997). Unfortunately in this study, recorded visit time could not be split in visit time at the exhibits and at the Tropical Forest. For that reason, how experiencing the Tropical Forest influenced learning could not be isolated.

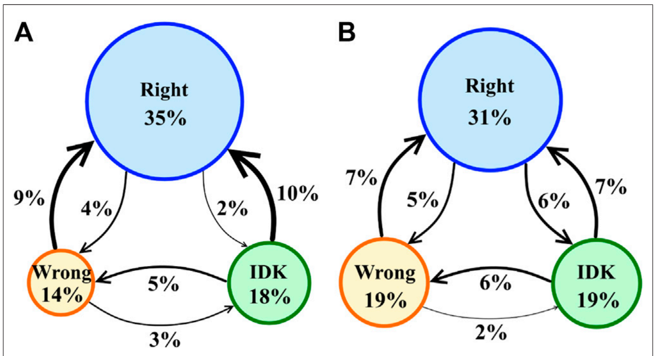

FIGURE 3 | Learning flow diagrams for Tūhura visitors who interacted **(A)** with the exhibits ($n = 409$, $n' = 1913$) and those who did not interact **(B)** with the exhibits (right, $n = 26$, $n' = 127$). n stands for the number of respondents, n' for total number of responses. Answers to the scientific content knowledge test were recoded as Right, Wrong and I Don't Know (IDK). All of the items (except the control question) were pooled together[20]. Responses were split into groups of visitors who interacted with the exhibits and visitors who did not.

Why there is a gender difference in prior knowledge for older visitors but not in younger visitors also warrants further study.

CONCLUSION

This research focused on the fundamental question of whether a single visit to a science centre results in science learning. As discussed earlier, in addition to content knowledge, learning comprises a rainbow of constructs, such as attitudes and engagement (Organisation for Economic Cooperation and

[20]In this section, n' means the sample size of the available number of responses, not number of respondents (n). For example, $n = 26$ visitors did not interact with Tūhura exhibits, but since each survey had five items, there were 130 possible responses. $n' = 127$ means three respondents skipped one item each.

Development, 2016). While all types or learning are valuable and contribute to an individual's cognitive, emotional, and social growth (Eaton, 2010) this study examined scientific knowledge. This construct is a core concept of scientific literacy (National Academies of Sciences Engineering and Medicine, 2016) that can be reliably assessed with multiple-choice questionnaires (Brady, 2005). However, objective testing methods are commonly considered inappropriate in informal venues (e.g. National Research Council, 2009; Fenichel and Schweingruber, 2010), relying its assessment mainly on self-reporting (National Research Council, 2009). The issue is testing in informal environments without alienating visitors.

Our recommendations for researchers who desire to use a formal test in an informal setting, are listed below. The first three recommendations are especially important when surveying young children.

1) Provide visitors with a friendly environment for testing,
2) Word questions such that they are clear, non-threatening, short and unambiguous,
3) Keep the survey as short as possible with the formal test in the middle,
4) Pilot the survey and pay attention to any discomfort of visitors; discard the method if signs of discomfort are detected,
5) Modify the questionnaire if needed,
6) Matched pre-post responses (having the same set of questions before and after with the same respondents) allows for direct pre-post comparison, but may also "cue" visitors; depending on available time, number of respondents and needs, consider alternatives, such as splitting samples.

Using the guidelines above, we managed to reliably assess content knowledge minimizing the bias of self-reporting. Unsurprisingly, prior scientific content knowledge, as measured by this study's instrument, increases with age during childhood and adolescence (during the years of formal schooling). It then reaches a plateau in adulthood. An important finding in this study was that learning content knowledge at the science centre was independent of age. When exhibits are engaging for people of different ages, nobody is too young or too old to learn from a visit to the science centre.

Gender did not play a role in prior content knowledge of young children, but adult females in this study showed significantly lower scientific content knowledge for these physics-related questions than males. Expanding on the multiple reasons that can cause a gender gap goes beyond the goals of this study, but one of the reasons may arise from personal choices related to females having less interest in physical sciences than boys (Osborne and Dillon, 2008; Krapp and Prenzel, 2011). A deeper discussion will be presented elsewhere.

Interactivity is another factor that heavily influences learning in science centres. A learning flow diagram helped visualize how answers move among the right answer, the wrong answers and the I Don't Know option after the visit. Visitors who interacted with the exhibits were more likely to provide correct answers after the visit, while answers of non-interacting visitors moved randomly among the options.

Although analyzing the full spectrum of what learning science entails was not part of this study's aim, the content knowledge test was complemented by qualitative and quantitative data collected through three surveys using the same data collection methodology by the same researcher in the same year (2018). These data helped triangulating the results, providing evidence of learning. While only one third of visitors reported coming to the science centre to learn some science, most of them reported learning as a result of their visit, as measured by both the MOLI instrument (86%), the direct question (78%) and the scientific content knowledge questions. In the latter, mean scores of correct answers increased from 1.96 to 2.61.

Some of the quotes provided by visitors clearly show learning of physics content knowledge, either about something new or refreshing older memories. This learning occurred for all ages, including very young visitors. In addition, some quotes show visitors were able to take what they experienced at the science centre and extrapolate it to personally-relevant contexts.

The combined use of different items and qualitative responses makes a strong case that visitors learned formal physics content knowledge in a single visit to the informal setting of this case study. It could be said that the MOLI instrument provided a quantitative measure of the breadth, the multiple-choice questionnaire provided quantitative depth, and the open question added qualitative breadth and depth.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

DS, DH, and NL conceived the project of which this study is part. DS and NL and designed the study. DS collected and analysed all data. DH provided financial support for conference presentations of the project where feedback was provided. DS wrote the first draft of the manuscript. DS and NL contributed to manuscript extension and revisions. DS, DH, and NL read and approved the submitted manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.698691/full#supplementary-material

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Program Design Principles to Support Teen-Adult Community Conservation Efforts

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Researchers and practitioners have identified numerous outcomes of place-based environmental action (PBEA) programs at both individual and community levels (e.g., promoting positive youth development, fostering science identity, building social capital, and contributing to environmental quality improvement). In many cases, the primary audience of PBEA programs are youth, with less attention given to lifelong learners or intergenerational (e.g., youth and adult) partnerships. However, there is a need for PBEA programs for lifelong learners as local conservation decisions in the United States are often carried out by volunteer boards and commissions, which often have little formal conservation training. Intergenerational PBEA programs can provide an opportunity to bring together, in the case of this study, the unique skills and knowledge of teens (e.g., tech-savvy) and adults (e.g., knowledgeable of local community issues) that can lead to innovative ways of addressing real world endeavors that are relevant to participants and their communities.

This study describes a program model that offers structured learning opportunities that support intergenerational partnerships (teens and adults) as they contribute to community conservation efforts. We used a design-based research approach to develop and refine program design principles and communication pillars for the purpose of supporting successful teen-adult conservation projects, positive participant experiences, and science identity authoring. The principles and pillars drew on identity, cultural learning pathways, and community conservation research literature as well as previously collected participant interview data from our intergenerational PBEA program. We outline four design principles and four communication pillars that are critical to facilitate collaborative teen-adult environmental action efforts and serve dual functions of providing program guidance and participant support. The aim of these principles and pillars are to establish collaborative team partnership norms that resist traditional hierarchical teen-adult relationships. Further, the principles and pillars consider how partners can draw on their interests, experiences, and knowledge of community, and utilize these assets along with conservation science disciplinary practices to accomplish meaningful science pursuits; thus facilitating how they identify themselves as contributing to science endeavors. Exemplar data and literature that support each principle and pillar are provided, and future extensions of these principles are discussed.

Keywords: communication pillars, community conservation, design principles, environmental action, science identity, intergenerational, lifelong learning, place-based

INTRODUCTION

The critical need for lifelong learners to participate in community conservation or place-based environmental action (PBEA) is motivated by the urgency to expand capacity to address emerging environmental issues (Horwich and Lyonm, 2007; Bonney et al., 2009; Ohmer et al., 2009; Short, 2010; Kransy, 2020), cultivate science-literate and civically engaged community members (Schusler et al., 2009; Short, 2010; Edwards, 2014; Kransy, 2020), and promote positive youth development and academic achievement (Schusler and Krasny, 2010; Schusler, 2015). Community conservation projects are efforts that are carried out by multiple community stakeholders that aim to protect, conserve, or improve local environments (Horwich and Lyon, 2007; Ohmer et al., 2009). PBEA programs support participants as they deliberately contribute to decision making, planning, implementation, and reflection of efforts intended to achieve a specific environmental outcome situated within their communities (Emmons, 1997; Schusler et al., 2009). Both participatory- and action-oriented approaches fall within the "democratic" paradigm of environmental education, aiming to enable learners to reflect upon and address social aspects of environmental problems that are relevant and meaningful to them (Schusler and Krasny, 2010). Examples of environmental action or community conservation include developing urban gardens in vacant lots to provide fresh produce to the community (Ohmer et al., 2009), erosion control along a stream bank in response to high levels of sedimentation (Tompkins, 2005), and monitoring black bear-activity patterns and habitat use in public areas to educate community members to reduce human-wildlife conflicts (e.g., Alegi et al., 2017).

Researchers and practitioners have identified numerous benefits of PBEA programs at both individual and community levels. These outcomes include promoting youth civic and professional development, fostering STEM (i.e., science, technology, engineering, and mathematics) identity and efficacy, developing a sense of place and nature connectedness, building social capital, and contributing to environmental quality improvement (Ohmer et al., 2009; Schusler et al., 2009; Short, 2010; Kransy, 2020; Rodriguez, 2020). Developing a sense of place can help participants feel a stronger connection to their environment, understand themselves as shapers of their environment (Ducre, 2013), and develop an appreciation for local resources; thus, combating deficit thinking about communities (Thomspon et al., 2020). Further, PBEA programs that specifically facilitate the co-design of the scientific or conservation project have a greater potential of meeting the needs of the community members, while also advancing conservation strategies (Golumbic et al., 2019; Senabre Hidalgo et al., 2021).

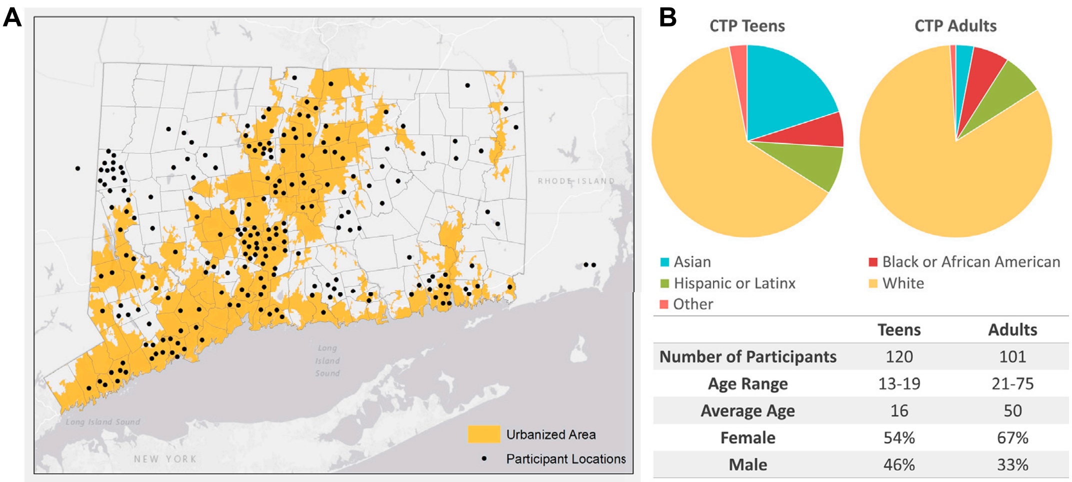
In many cases, the primary audience of PBEA programs are youth and adolescents, with less attention given to lifelong learners and intergenerational partnerships (Edwards, 2014; Peterson et al., 2019; Rodriguez, 2020). However, there is a need for PBEA programs for lifelong learners as conservation and land use decisions are often carried out at the local level by volunteer boards and commissions throughout the United States (Arnold, 2000; Nolon, 2014), which typically have little support in the form of education in natural resources or conservation science. PBEA programs that educate and partner adult conservation volunteers and adolescents may more effectively promote multiple outcomes of PBEA education. Specifically, intergenerational PBEA programs provide an opportunity to bring together the unique skills and knowledge of teens (e.g., tech-savvy) and adults (e.g., knowledgeable of local community environmental issues) that can lead to innovative ways of addressing real world pursuits and challenges that are relevant and important to the participants and their communities.

In this study, we describe design principles and communication pillars of a PBEA program model that offers structured learning opportunities to support intergenerational (teen and adult) community conservation efforts. Our work is situated within a design-based research (DBR) paradigm (Design-Based Research Collective, 2003), which provided a means to develop and refine program design principles and communication pillars that support the overarching goals of our PBEA program of promoting successful teen-adult volunteer environmental action efforts and intergenerational STEM identity authoring (e.g., the ways in which teens and adults come to view themselves as individuals who are capable of, willing to engage in, and have access to supportive social structures that recognize their skills and capabilities to contribute to meaningful STEM pursuits). Consequently, we outline four design principles and four communication pillars that have emerged from our work to date, describe the iterative design-based process undertaken for their development, and further detail and reify the principles and pillars with example case studies.

METHODS

Learning Environment

The University of Connecticut's Conservation Training Partnerships (UConn-CTP) (UConn NRCA CTP, 2021) is a NSF-funded STEM and PBEA program that uses an



	Teens	Adults
Number of Participants	120	101
Age Range	13-19	21-75
Average Age	16	50
Female	54%	67%
Male	46%	33%

FIGURE 1 | (A) A distribution map showing the locations (black dots) of each UConn-CTP participant's community, which serves as the general location of each conservation project, throughout Connecticut and nearby states. Participants' communities fall along an urban (yellow shading) to rural (no shading) gradient, thus providing diverse context for community conservation projects **(B)** Demographic data from 221 UConn-CTP teen and adult participants.

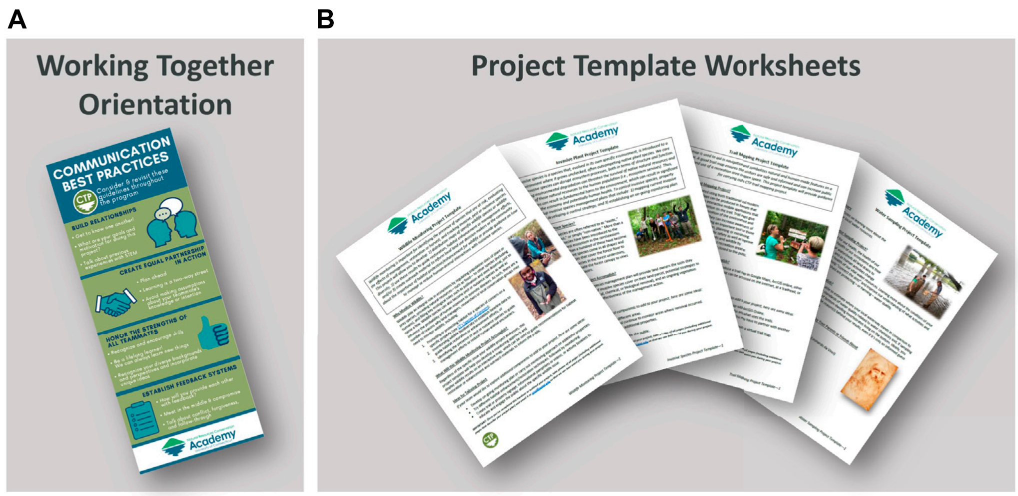


FIGURE 2 | Images of two types of participant project support documents **(A)** communication best practices to facilitate collaborative intergenerational teamwork, presented during a participant orientation and revisited throughout the program, and **(B)** project planning templates to provide a heuristic approach for scaffolding intergenerational team project development. See all original documents in the Supplementary Material.

intergenerational partnership framework to connect teens and adults from different backgrounds (**Figure 1**; e.g., participants from communities that span an urban to rural gradient) and empowers them to understand and address local environmental issues. First, intergenerational teams are formed prior to the start of the program (often recruited and formed by program faculty). These intergenerational teams comprise any combination of 1–4 high school students and 1–4 adults. Adults may be community or conservation volunteers (including land use decision makers from municipal commissions or land trusts), teachers, or family members, and may join the program with or without a prior connection to their teen teammates.

Next, the teen-adult teams attend a two-day immersive field workshop—held at different locations across Connecticut—where they begin to explore natural resource science concepts such as land use change, forest health, water resource protection, and biodiversity. Through hands-on field activities they explore how online mapping (geospatial) technology can be used to investigate conservation issues (Chadwick et al., 2018). Considerable time during the workshop is also dedicated to guiding the teen-adult teams through brainstorming and designing local conservation projects tailored to their interests and their community's needs. Through multiple iterations of the UConn-CTP workshops (10 total), we have developed web-based participant project support resources (**Figure 2** and Supplementary Material; UConn CTP Resources, 2021). These include a past participant project showcase to orient new participants to the scope of conservation efforts undertaken by previous participant cohorts (UConn NRCA Projects, 2021), project planning templates (**Figure 2B** and Supplementary Material) that can be used as a heuristic approach for scaffolding initial conservation project development, and communications best practices to facilitate collaborative discussions and teamwork (**Figure 2A** and Supplementary Material). We note that the project planning templates are not meant to provide participants with a step-by-step approach to conducting a conservation project around a particular topic. Rather, the templates serve to provide guidance to participants about the different aspects of the project (e.g., locations of the project, timeline, disciplinary practices, and equipment/resources needed) they should consider in order to thoroughly developed their project tailored to their community needs and individual interests.

After the workshop, UConn-CTP teams carry out their community conservation projects throughout the summer, fall, and winter (most projects spanning from July to March). Projects are diverse and have included wildlife monitoring, trail mapping, invasive species management, water quality testing, and habitat restoration. Further, all projects employ one or more of the geospatial and conservation techniques learned during the workshop. UConn-CTP faculty provide significant post-workshop support through professional guidance, technical assistance, community connection, and access to a vast resource collection (UConn CTP Resources, 2021). Collectively, 221 teen and adult participants have carried out 71 community conservation projects throughout Connecticut since 2017 (**Figure 1**), with many UConn-CTP teams showcasing their work at a statewide environmental conference in March (see UConn NRCA Projects, 2021 to explore project topics and duration).

Design-Based Approach

The need for our design principles and communication pillars became apparent over time as we recognized the beneficial and challenging ways in which teens and adults engaged both with us and with each other during their community conservation projects (e.g., hierarchical relationships, different means of communicating). As such, the purpose of the principles and pillars was to support project completion, positive participant experiences, and STEM identity authoring.

Creation of the design principles and communication pillars was guided by design-based research (DBR) principles (Design-Based Research Collective, 2003), which embraces the connections between design and real-world contexts. This requires program designers to think flexibly about each aspect of the program, participant experiences and the relationship between program elements, design, and learning outcomes (Barab and Squire, 2004; Brown, 1992). We began by reflecting on the overarching goal of our STEM and PBEA program (UConn-CTP), which is to better understand intergenerational STEM identity authoring (e.g., the ways in which teens and adults come to view themselves as individuals who are capable of, willing to engage in, and have access to supportive social structures that recognize their skills and capabilities to contribute to meaningful STEM pursuits). Our DBR approach for the design principles and communication pillars is also guided by the high-level conjecture (Sandoval, 2004; Sandoval, 2014) or informed understanding that for participants to craft a STEM identity for themselves, intentionally designed structures and supports must exist for participants.

Initially, we used the following four considerations to propose design principles that could support intergenerational learners both in the workshop and in subsequent group work during their conservation projects:

1. The literature and our experience informed how we conceptualized intergenerational identity authoring happening in our program;
2. Previous program evaluations and informal observations stemming from over 70 UConn-CTP conservation projects;
3. Existing literature about informal STEM learning, STEM identity authoring, and cultural learning pathways; and
4. Prior experience with group interaction and project completion in classroom and university settings.

After articulating initial designs separately, the second and third authors came together to review and critique the collection of proposed design principles that emerged. When evaluating the initial proposed principles, the second and third authors continually reflected on STEM identity authoring and evaluated each proposed principle for its ability to help participants develop this view of themselves. It became clear that some principles overlapped while others did not. Additionally, some design principles were oriented to supporting intergenerational learners in developing their projects, while others focused on supporting productive communicative interactions among intergenerational teammates, all with the goal of developing STEM capabilities, recognition of these capabilities, and a supportive social network. This gave rise to the distinction between the design principles and communication pillars. The resultant design principles and communication pillars were subsequently shared with UConn-CTP faculty and further refined for their ability to support program goals and enhance participant experience. Next, we used interview data from UConn-CTP intergenerational teams (8 teens and 7 adults) that were collected at multiple points during and after the completion of the intergenerational team's conservation project to study intergenerational identity authoring (Rodriguez et al., 2020; Rodriguez, 2020; Campbell et al., 2021; Simmons et al., in review). These data were used to determine the extent to which each design principle could be mapped to previous benefits or challenges referenced by participants.

After evidence of the need for, and benefit of, each principle was established by the literature and participant data, the design principles and communication pillars were subsequently mapped

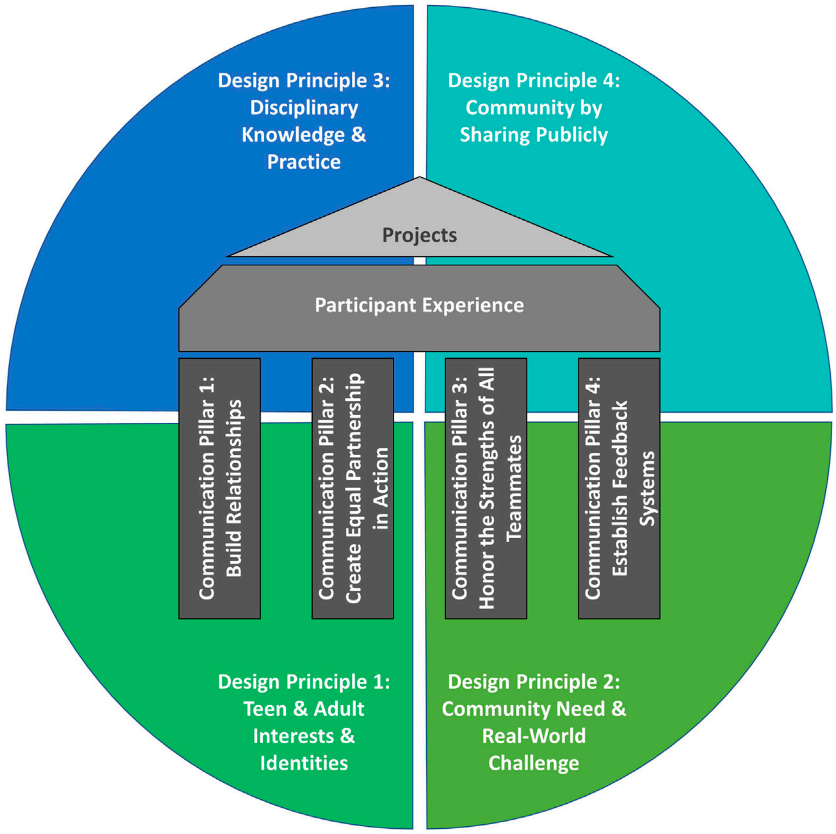


FIGURE 3 | Diagram of our program design principles and communication pillars that facilitate collaborative intergenerational community conservation projects. The principles and pillars serve dual functions of guiding program features and providing participant support. As such, the four design principles (underlying circle) guide all our program strategies. The four communication pillars support the positive experiences of our participants by disrupting traditional uneven power structures in intergenerational partnerships and providing strategies for collaborative team norms, thus allowing all teammates to engage in conservation work more deeply together.

to program features, such as the project planning templates (**Figure 2** and Supplementary Material) and workshop or conservation project facilitation strategies to determine where these principles and pillars already exist or where they might be added to further improve participants' STEM identity authoring and successful community conservation efforts.

RESULTS

Design Principles

The four design principles encourage our participants to connect their projects to: 1) both partners' interests and identities, 2) community needs and real-world challenges, 3) current disciplinary knowledge and practices, and 4) community by sharing it publicly at local events or conferences (**Figure 3**). Below, we describe each design principle and support them with 1) relevant literature, 2) case studies that exemplify how the design principles are taken up in participant projects, and 3) participant interview data that demonstrate the importance of each principle. We note that the quotations used the *Participant Interview Data* sections do not always come from the participants described in the *Case Study* sections in order to provide additional support for each principle.

Design Principle 1: Connect Project to Teen and Adult Interests and Identities

The first principle encourages both teen and adult participants to connect their community conservation project to their prior experiences. This helps ensure that the project draws on the assets of both partners, avoiding deficit framing and allowing for more expansive and meaningful ways for participants to engage in science and conservation. This asset-based approach facilitates STEM identity authoring (Rodriguez et al., 2020, Rodriguez, 2020), which in turn can promote lifelong STEM learning and participation (Carlone & Johnson, 2007).

Supporting Literature

This design principle finds its roots in the identity and cultural learning pathways literature. Here, identity can be understood as the negotiated self-narrations or self-construals individuals and others use to answer questions about who an individual is (Lee, 2017). A STEM identity refers to how a person identifies with a STEM field and is recognized as being a person who belongs in and is capable of understanding and applying disciplinary concepts, participating in pursuits of consequence, and contributing to that field. The development of a STEM identity is important in deepening an interest in a STEM field into perseverance in the field (Carlone and Johnson, 2007). Additionally, as Meyer (1998) notes, "knowing something, then, is a cultural experience that strengthens or fractures culture," thus culture must be considered and shared as STEM identity is developed (p. 22). Here, culture can be understood more broadly in alignment with Bang et al. (2017) as, "ways of knowing, talking, valuing, and acting as we live out our day-to-day lives inside family and community" recognizing that "human beings make sense of the world in ways that are both similar and different" (p. 35). Consequently, cultural learning pathways theory (Bell et al., 2012) considers the multidimensionality, fluidity, and plurality of identity authorship (Barton and Tan, 2010; Vareles et al., 2012). Here, a cultural learning pathway recognizes that learning happens across space and time over a lifespan in the pursuit of personal goals. Central to cultural learning pathways are how interests can launch, be strengthened, and shape identity through situated events that help individuals (i.e., teens and adults) negotiate their self-construals of who they are. Given this, as a way to support identity authoring, this design principle prioritizes connecting the focus of participants' community conservation efforts to the interests and identities of teens and adults.

Case Study 1: Geologic Natural History of a State Park

The following case study demonstrates how intergenerational teams can incorporate science and environmental interests as well as other non-science interests such as art, technology, and other extracurricular interests, into their conservation projects. During a project brainstorming exercise, the intergenerational team in this example who did not know each other prior to the program—discussed the teen's interest in geology and the adult's enjoyment of hiking and connection to state parks as an environmental state agency employee. They combined their unique interests to create an online interactive map of a popular state park trail so that the public can take a virtual hiking tour and learn about various geological features along the trail. This team also leveraged their interest in photography to incorporate a creative element to their project by including photographs in pop-up windows that interpreted what each geological feature resembled. For example, one rock outcrop was compared to an elephant and another to a volcano. This is just one illustration of how we can allow participants to explore expansive ways of engaging in environmental efforts and afford participants opportunities to draw on their multiple intersecting identities in completing their projects.

Participant Interview Data Supportive of Design Principle 1

- "Do something you care about... just do something fun, and do something that you enjoy, and that you're passionate about." UConn-CTP Teen
- "I was interested in learning more about the technology aspect and working on another project that involved environmental issues because I'm really interested in that kind of stuff... so I can map out different areas of trails and things like that, where I find interesting things to come back to." UConn-CTP Teen

Design Principle 2: Connect Project to Community Need and Real-World Challenges

Through principle 2, participants connect their project to a community need and a real-world challenge. Not only does this set up the project to have real community benefits, but it provides participants with the opportunity to see the power in applying their disciplinary and action-oriented knowledge in the context of addressing community issues that are relevant to them, further consolidating the first principle.

Supporting Literature

Recently, STEM education and citizen science researchers have noted the importance of engaging learners in meaningful pursuits, like explaining real-world phenomena or solving problems of consequence (National Research Council, 2013; Krajcik, 2015; Golumbic et al., 2019; San Llorente Capdevila et al., 2020; Senabre Hidalgo et al., 2021). Other social scientists (e.g., Vygotsky, 1987) have noted the importance of a focus on why people are engaged in activities or the meaningfulness of pursuits (e.g., to solve a conservation problem; explain a real-world phenomenon), since these pursuits provide a framework for what competences or performances matter and why (Hyysalo, 2005). In this design principle, we prioritize connecting teen and adult projects to community need and real-world challenges to both draw on a combination of notions of relevancy and authenticity in supporting learners in informal learning contexts (Dierking et al., 2003) and to support teens and adults in deliberately contributing to decision making, planning, implementation, and reflection to achieve a specific environmental outcome situated within their communities (Emmons, 1997; Schusler et al., 2009; Golumbic et al., 2019; Senabre Hidalgo et al., 2021). This is important, since Rivera Maulucci et al. (2014) argue, that when we ground learning and participation "in students" (and adults') lives, their identities develop in the context of exploring problems that are meaningful to them and to their communities" (p. 1123). Further, when connecting projects to community, it is critical that community voice is recognized and honored, and that any project aligns with community values (Metcalf and Style, 2019).

Case Study 2: Urban Tree Reuse Project

In this case study, the teen-adult team did not know each other before joining UConn-CTP but lived in the same urban community. The student had an interest in forestry and the adult partner, as a manager of a park sustainability program, was aware of city trees scheduled for removal after having been infected by emerald ash borer beetles. Through further research, the team recognized that the proposed wood chipping method for wood disposal would result in the loss of an important source of carbon storage and a valuable natural resource product. Together they developed an urban tree reuse project where they worked with the city to recuperate the ash wood, crafting beautiful benches that were then placed back into local parks. This participant project has continued to be active beyond the support of the UConn-CTP program.

Participant Interview Data Supportive of Design Principle 2

- “We’ve been going along with our removing the dead trees, reusing the lumber, and then replacing those trees. It’s a whole lot of conservation and community benefits.” UConn-CTP Teen
- “Going through this project and being with it for such a long time and seeing it come to fruition, and having all these grants and stuff, like coming into play, it’s like it gives me a deeper connection to my local community.” UConn-CTP Teen
- “Seeing this create this opportunity for kids to get involved in their own community, and make those connections with leaders in the community and the local government or anything like that, is just awesome.” UConn-CTP Adult

Design Principle 3: Connect Project to Disciplinary Knowledge and Practice

Principle three encourages participants to utilize knowledge and practices of experts when planning and implementing their conservation projects. These connections allow for partnerships with a range of people from a variety of fields, including scientists and community organization leaders.

Supporting Literature

This design principle is shaped by social practice that happens in what Lave and Wenger (1991) and Wenger (1998) referred to as “communities of practice” where identity is authored (Carlone and Johnson 2007). Communities of practice can be understood as groups of individuals with common interests (e.g., hobbyists) or engaged in common forms of activity (e.g., naturalists) who over time have developed competencies (i.e., knowledge) and practices (i.e., ways of working at knowing or solving problems) supportive of accomplishing their pursuits. Gee (2000–2001) points to how engaging in a community of practice, initially on the periphery and more centrally over time, shapes the “kind of person” one is seeking to be and enact. In this, there is a recognition that one cannot successfully enact a particular identity that is legitimized by oneself and others without drawing on relevant competencies and practices that are suited for meeting group-level or a community of practice’s needs. As such, this design principle aims to connect teen and adult learners to communities of practice (e.g., amateur birders) to both leverage disciplinary knowledge and practice to accomplish their desired pursuits, while also connecting them to communities where identities are constructed. Supporting structures in the way of communities of practice and training on disciplinary practices and protocols is also a key factor to for successful citizen science projects (Liberatore et al., 2018; San Llorente Capdevila et al., 2020).

Case Study 3: The Beavers of Mendell’s Folly

This teen-adult duo wanted to highlight the importance of a beaver-created wetland on a land trust property. The adult partner was a land trust volunteer, and her teen partner’s former middle school teacher. For the project, they researched scientific literature and reached out to several relevant experts to gain insight and understanding about the role of beavers as ecosystem engineers. For example, they toured the University of Connecticut’s Biodiversity Research Collections to learn more about local wetland-associated mammals, and conducted interviews with a graduate student studying wetlands and a biologist at a nearby nature center. They integrated these varied resources into an Esri StoryMap (geospatial technology taught at the UConn-CTP workshop), which allowed them to convey a multitude of information using a storytelling strategy—including text, multimedia, and maps—to engage and inspire a broader audience. The value of connecting their project to disciplinary knowledge and practice was evinced by an award from the 2020 EsriUser Conference Student Map Competition for their StoryMap (Lu and Arnini, 2020).

Participant Interview Data Supportive of Design Principle 3

- “Why should we just chip up the wood and put it in the landfill where all that carbon eventually goes back into the atmosphere when we can use that wood to create furniture, like a bench or a chair, that will keep that carbon sequestered longer and have this extra benefit of just being an awesome piece of furniture.” UConn-CTP Teen
- “I have definitely gotten a bit better at birds. I can like transfer grips, and I can hold birds better. . . I learned about stopover sites, which was something like—it can be extrapolated from knowing anything about migration, but I hadn’t really learned about, in detail.” UConn-CTP Teen

Design Principle 4: Connect Project to Community by Sharing Publicly

The fourth principle of sharing the project with the community and broader public serves three goals: 1) it informs the public about community members who are actively engaged in community improvements, 2) it publicly recognizes the accomplishment of both partners, and 3) it highlights the opportunity for other community members to contribute. Similar to design principles 2 and 3, this principle has a dual purpose of both supporting teen and adult identity authoring and supporting community conservation efforts. While UConn-CTP project final products may range from a poster, article in a local newspaper, an Esri StoryMap, or a park bench, teen and adult participants are encouraged and supported to share their projects publicly. For many, this means presenting at a statewide conservation conference as well as sharing locally via in-person events (*e.g.,* town halls, public fairs, community outreach events at land trusts, libraries or schools) or through online/social media platforms of local community organizations.

Supporting Literature

Public communication of local environmental efforts by community members is essential to bring awareness of issues where they matter most as well as build social capital among community members (Conrad and Daoust, 2008). Increased social capital within a community can play a key role in increasing and sustaining stakeholder involvement in future community efforts (Conrad and Daoust, 2008). Most important in relation to identity authoring, this design principle aims to afford teens and adults recognition. Recognition is important since it can be understood in relation to identity as the juxtaposition of a person's internal designations (how they see themself) and the social designations ascribed by others (how they are seen by others) (Carlone and Johnson, 2007; Hazari et al., 2015).

Case Study 4: Municipal Water Conservation Education

One daughter-mother team focused their conservation efforts on aiding their town's application to become a certified "SustainableCT" town. They contributed to this effort by developing and distributing a survey to better understand community members' views on water conservation, which later guided water conservation educational materials distributed to town residents. As such, this team authored several articles in local news outlets, both online and in print, to reach town residents more broadly to distribute the survey. They also presented the results of the project at a town council meeting so that their findings could be integrated into the town's sustainability initiatives. Following the UConn-CTP program, the teen continued her efforts, and paired with an elementary school to provide water conservation education to children. Through this example we aim to emphasize the importance of external recognition in building participants' confidence and identity such that they feel capable of continuing their conservation work beyond our program.

Participant Interview Data Supportive of Design Principle 4

- "During that project, I published a few articles in the local newspapers about why we should care about this issue. That was really enjoyable to me spreading awareness, so I continued to try and write articles about conservation in general and send them to local newsletters." UConn-CTP Teen
- "I think people were really interested in what I had to say. I was a bit surprised by how open and supportive and interested people were, especially 'cause I was a young person presenting to these all the people that came to the event were basically older adults and I was just I didn't think they were gonna take me as seriously as I thought they as they actually did." UConn-CTP Teen
- "Oh, it was a very proud moment to see her with three or four other presenters from different fields, from the water company, the town selectman,. . . the sustainable board, the town's sustainable advisory board, and a couple of other participants who also presented." UConn-CTP Adult

Communication Pillars

The communication pillars were developed to support productive interactions among intergenerational teammates (**Figure 3**). These pillars were introduced to intergenerational teams at the beginning of the summer workshop. Participants were asked to consider them often and revisit them throughout the program in relation to their interactions with their teen or adult partner. Each pillar is introduced briefly, alongside example participant quotes indicative of how each can manifest in the interactions among intergenerational teammates.

Communication Pillar 1: Build Relationships

Participants are shaped by their culture and previous experiences with STEM. Taking the time to explore participants' interests and experiences strengthened their connection to the project and helped strengthen their STEM identities. Further, the relationship building process allowed participants to build trust in each other, which was critical to the success of their project. The following prompts introduced participants to this pillar:

- Get to know one another!
- What are your goals and motivation for doing this project?
- Talk about previous experiences with STEM.

Participant Interview Data Indicative of Communication Pillar 1

- "It's nice to see her grow as a student. She didn't say a word to me the first time we met, by the way. She's very quiet. Seeing her grow as a person who felt comfortable telling me something as simple as, "I think the wording should be different here," she wouldn't have told me that back in the summer." UConn-CTP Adult
- "I want to learn what she knows. She says she's a bird expert or something. I just want to learn more science. I'm not—this is all really new to me." UConn-CTP Teen
- "Now knowing more about her personal interests, more about what she's interested in doing with her life, I can better support that." UConn-CTP Adult

Communication Pillar 2: Create Equal Partnership in Action

The intergenerational partnership aspect of UConn-CTP is designed to disrupt traditional teen-adult interactions where power disproportionately resides with adults. Reframing this experience as a learning experience for both partners and planning for an equal partnership shaped the way intergenerational teams interacted and how power was more evenly distributed across teens and adults. The following prompts introduced participants to this pillar:

- Plan ahead.
- Learning is a two-way street.
- Avoid making assumptions about your teammate's knowledge or intentions.

Participant Interview Data Indicative of Communication Pillar 2

- "From that point of view, we were well-matched because nobody's feeling like they are overwhelmed or aren't doing enough." UConn-CTP Adult

- "A thing I do like in science that it is a team effort, not like, it's not like math, or where you have to work independently. I like the different ideas coming across, so what (one partner) knows, I might not know, what (another partner) knows, I still might not know, or what they don't know, I can enlighten them, so I feel I love the team effort, and its collaboration." UConn-CTP Teen

Communication Pillar 3: Honor the Strengths of All Teammates

Participants bring a diverse set of prior experiences and a range of knowledge and ways of knowing to their project. Recognizing the knowledge, ways of knowing, and strength of an individual participant bolstered their STEM identity and allowed them to incorporate unique ideas to find innovative solutions. The following prompts introduced participants to this pillar:

- Recognize and encourage skills.
- Be a lifelong learner. We can always learn new things.
- Recognize your diverse backgrounds and perspectives and incorporate unique ideas.

Participant Interview Data Indicative of Communication Pillar 3

- "I think we both share listening to each other's ideas. . . I don't feel like either one of us tries to take the lead. I feel like depending on what the task is. Because it's the bench and Marcus (pseudonym) has made one before, he may take the lead in that portion, but if it's, say, it's using a tool, or sanding, or measuring, or cutting, or something that I've done before or am comfortable with, he allows me to take the lead on that." UConn-CTP Adult
- "I'm trying to put what I already know into the project. I'm trying the best that I can. She knows a lot more than I do. I'm trying to understand, and I don't want to make her do all the work. I want to be able to help." UConn-CTP Teen

Communication Pillar 4: Establish Feedback Systems

Effective teamwork relies on effective communication. This is especially important since individuals of different ages and cultures have different expectations about communication, collaboration, and perceptions of time that can potentially lead to conflict if not planned for when making explicit guidance for communication and feedback. This is important, since participants may make assumptions about the value or intention of their teammates that negatively impacts their impression of their teammate. Through establishing feedback systems early in the process, participants had a principled plan for communication. The following prompts introduced participants to this pillar:

- How will you provide each other with feedback?
- Meet in the middle and compromise.
- Talk about conflict, forgiveness, and follow-through.

Participant Interview Data Indicative of Communication Pillar 4

- "I think that was a big having to learn how to communicate effectively within our team and how to reach out. . . It was a good experiment in leadership and management and also just understanding what was best for the overall project and the team." UConn-CTP Adult
- "I will say that the students definitely kept me on track, especially Jackie [pseudonym]. "Cause she would text me, like, "I haven't heard from you about this." UConn-CTP Adult
- "I feel like the only problem there was communication just "cause we didn't really use any of the same mediums. Max and I would text or Snapchat each other and then we'd email Jillian (pseudonyms). It was kind of hard to organize everything." UConn-CTP Teen

CONCLUSION AND FUTURE DIRECTIONS

In our place-based environmental action program work to date, we have tried to design a program that addresses the critical need for lifelong learners, both teens and adults, to engage meaningfully in environmental action to address the urgent need for expansive local approaches to environmental issues (Horwich and Lyon, 2007; Ohmer et al., 2009; Short, 2010; Kransy, 2020) and support the fluid and intersectional STEM identity authorship of intergenerational learners (Rodriguez et al., 2020; Rodriguez, 2020). As reported, we have done this by supporting 221 teen and adult participants to carry out over 71 community conservation projects throughout Connecticut and nearby states since 2017 (**Figure 1**). Along the path to supporting the successful completion of these projects, we engaged in an adapted iterative DBR approach (Design-Based Research Collective, 2003) to develop and refine the program design principles and communication pillars that drew on existing research from identity theory (e.g., Gee, 2000–2001), cultural learning pathways (e.g., Bell et al., 2012), activity theory (e.g., Vygotsky, 1987), and community conservation research (e.g., Horwich and Lyon 2007; Ohmer et al., 2009). This literature foundation was considered alongside our previous experience as STEM and environmental educators and examined in the context of previously collected interview data. In the end, the formation of these design principles and communication pillars highlighted the need for creating space for participants to share their backgrounds and experiences and for program materials that made space for their culture in the planning process of their conservation projects.

While we have been able to establish the validity and usefulness of the design principles and communication pillars, we share these as the most recent iterations that we will continue to refine and improve, as design-based research is a cyclical process that requires testing and iteratively modifying interventions within real-world contexts to develop practical approaches. These principles and pillars are important foundations for undertaking aims of equitable participation within intergenerational community conservation efforts. They rely on STEM identity and cultural learning pathways research. We recognize that these design principles do not yet fully consider the environmental justice and anti-racist aims which we aspire to continue to learn about and center in our PBEA programs. Given this, we see our work as ongoing and invite others to engage critically with us as we seek to meet the goals of centering equity, inclusion, and belonging within PBEA programs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board, University of Connecticut. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

LC, NF, CA, CC, DD and JV developed and implemented multiple iterations of the UConn-CTP program, with guidance by TC, DM, LR and JS. JS and TC developed the conceptual framework of the design principles and communication pillars, and used previously collected interview data collected by LR and JS, with assistance by LC and NF. All authors contributed to the refinement of the design principles and communication pillars. JS, TC, LC and NF mapped and added the design principles and communication pillars into existing participant project support documents. LC, JS, TC, and NF led the writing of this paper, with additional contributions from CA, CC, DD, DM, LR and JV.

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SUPPLEMENTARY MATERIAL

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ORIGINAL RESEARCH
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High Pulse: Exploring the Exhibit Features of a Collaborative, Whole-Body Exhibition for Experiential Learning in Science Centers

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This research work explored how collaborative, whole-body exhibits affect science learning in informal out-of-school settings. Specifically, the study investigated how exhibit features guided visitors to engage actively in experiential exploration of the exhibition topics, and how these exhibit features guided visitors to make sense of the interaction and transform experiences into knowledge. The study took place at a science center in Denmark. The context was the PULSE exhibition consisting of eight individual exhibits that aimed at facilitating discussions on the importance of bodily activities for physical and social well-being. Together the exhibits formed the traditional parts of a family home and core family activities, for example, a kitchen for cooking. Each exhibit was built on experiencing through physical activity and revolved around one or several biological phenomena, for example, balance, coordination, and suppleness. All exhibits were designed for group interactions. The study explored the visitors' experiences with the exhibition using data from walking interviews with 34 visitor groups comprising a total of 108 visitors. Each exhibit was composed of a set of exhibit features, and the study analyzed how these features supported the experiential learning. The findings showed that the whole-body activities and group collaborations formed the greatest motivation to participate in the exhibition and, thereby, explore the themes of the exhibition. As regard the visitors' learning, most groups expressed the joy of physical movement, group work, and need of strategy planning to carry out the activities in their conversations, whereas only a few groups seemed to perceive and reflect on the biological phenomena presented. Due to the physically demanding activities and the required social collaboration, the visitors were not able to engage in in-depth explorations of the exhibition's scientific themes. In some exhibits where scientific information was incorporated naturally in the activity through interactive videos, the visitors talked about the themes as a natural part of the activity. Altogether, the findings have been used to outline a set of design principles for collaborative whole-body exhibits.

Keywords: exhibit features, collaborative, whole-body exhibition, experiential learning, science centers, mediational means and mediated action

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INTRODUCTION

Science centers are often described as the third generation of science museums, characterized by informal learning and interactive exhibits aimed at engaging visitors in understanding scientific laws, principles, and phenomena rather than presenting collections of scientific objects (Pedretti 2002; Friedman 2010). Typically, science centers include a combination of interactive exhibits that invite and respond to visitors' actions and hands-on exhibits that do not offer interaction feedback but allow visitors to touch and handle them. In science centers, visitors are not regarded as passive recipients but acknowledged as actively involved in the acquisition of knowledge (Hooper-Greenhill 2000).

Wellington (1998) described two types of exhibits usually found in science centers: experiential and pedagogical exhibits. In experiential exhibits visitors learn something by relating bodily to physical phenomena, whereas in pedagogical exhibits visitors learn by being taught something, that is, by formal learning. The idea of experiential exhibits originates from the philosophies of experiential education emphasizing the importance of personal experiences for learning (Kolb, 1984; Dewey 2008a). This form of learning is informal in that it is promoted by the visitor's own reflections on her or his experiences.

Experiential exhibits are interactive exhibits "in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input" (McLean, 1993, 93). Bitgood (1991) specified that interactive exhibits allow physical interaction in which the visitor's response to the exhibit produces a change in the exhibit, for example, lighting, sound, and objects' position. He distinguished between simple *hands-on exhibits* that allow the visitor to for example, touch objects, *participatory exhibits* that prompt a response and an outcome by comparing it with some other response or standard, and *interactive exhibits* that prompt a response which changes the stage of the exhibit. This change is generated by the visitor's actions.

We know from previous research that it is not possible to prescribe interaction behavior or outcome in experiential exhibits because visitors approach interactive, open-ended exhibits differently (Allen, 2004). Allen and Gutwill (2004) argued that multiple interactive features may overwhelm, disrupt, or displace visitors' attention and in the end disturb or prevent the visitor's experience. Dancstep et al. (2015) suggested that whole-body exhibits, compared to tabletop exhibits, each have their own strengths with respect to visitor experience measured by physical effect, attitude, scientific thinking, and memorability. In their study, immersive, whole-body interactive exhibits fostered slightly more positive attitudes particularly in relation to using the exhibits with others (social interactions), whereas tabletops held visitors' attention for longer periods of time and prompted more utterances and reasoning about the scientific phenomena compared to whole-body interactive exhibits. In regard to memorability, there were few differences between the two exhibit types. Dancstep and her coauthors summed up by emphasizing that we still need more research about immersive, whole-body exhibits.

Concerning social interactions, most studies have focused on the effect and outcome of the social interaction between visitors. Several studies investigated family groups and intergenerational social interaction in interactive exhibitions. These studies showed that grandparents and other caretakers were important teachers and facilitators for the visitor experience (Blud, 1990; Sanford, Knutson and Crowley, 2007; Gutwill and Allen, 2010). Others studied groups of children, also with the aim of understanding how they collaborate (Mcclafafferty and Rennie, 2012; Yoon et al., 2013; Piscitelli and Penfold, 2015; Skydsgaard, Andersen and King, 2016). Overall, these studies suggested scaffolding as essential in interactive exhibitions, provided through collaboration, digital augmentations, or posted questions.

The aim of this exploratory study was to extend our knowledge about one particular form of exhibit design at science centers, namely, interactive, whole-body, and collaborative exhibits. The goal was to investigate how a set of multiple exhibit features guided visitors to engage actively in exploration of the exhibition topics and make sense of the social whole-body interactions and transform their experiences into knowledge. The study investigated the visitors' experiences while interacting with the exhibits and the experiential quality of exhibit features:

1. How did the exhibit features guide visitors to engage collaboratively and interactively in experiential exploration of the exhibition topics?
2. How did the exhibit features guide visitors to make sense of the collaboration and interaction and transform experiences into knowledge?

The first research question addressed how the visitors reacted emotionally to the exhibit features and interacted with them and with one another. The second question explored the visitors' sensemaking regarding the lessons learned that may be distilled from the reaction, interaction, and conversation between the group members.

The remainder of this article is organized as follows: *Theoretical Framework* presents the theoretical framework. The case and research methodology is presented in *Research Design*. *Findings* covers the results on how visitors used and experienced the exhibition. *Discussion and Implications* discusses how the exhibit features and activities contributed and can be improved to support the visitor experience, and the research conclusions are presented in *Conclusion*.

THEORETICAL FRAMEWORK

In this section, we sketch the theoretical background of our study. We start with presenting our understanding of the concept of experience and how this understanding informed our approach to the experiential qualities of the exhibit features. Experiences are generated by direct contacts with the environment. Seminal for understanding the experiential qualities of an exhibit is, thus, the reactions and interactions of the experiencer to the surroundings. In the second part of this section, we present core elements of sociocultural theory to describe exhibit features which have distinct experiential qualities.

Experiences are never simple responses brought about by some identifiable stimuli. Experiences are situated. First, they occur in a specific situation and their occurrence depends as much on the situated actions of individuals as on their reactions to the situation (Dewey, 2008a; Jantzen, 2013). Experiences presuppose a doing as well as an undergoing by the experiencer. Second, the quality of new experiences depends on prior experiences and on the expectations to the situation that these have fostered. Prior experiences generate a norm on which the new situation is assessed (Kahneman, 1999). New experiences occur when the situation differs from this norm.

Experiences, therefore, imply two temporal dimensions. On the one hand, experiencing is instantaneous by being bound to the present in which something happens. This immediacy of experiencing is physiologically and affective in character. But on the other hand, "an experience" may be long-lasting by becoming memories of events having occurred in the past. "An experience" integrates the lessons learned from experiencing with existing information (the norm), hence leading to an increased or altered understanding of the world and/or oneself, which can be utilized in future experiences (Dewey, 2008b). This process is sensemaking and captures the learning dimension of experiencing. Thus, experiential learning occurs when the immediacy of affective changes is transformed into a higher-order purposeful action (i.e., meaning) that forms the basis of new know-how (Kolb, 1984). Learning is the lasting outcome of the museum experience and is the result of the combination of what takes place at the exhibit and what the individual visitor makes of it (Ansbacher, 1998).

In this respect, an experience is complex, coherent, and a whole that integrates physiological, emotional, and cognitive dimensions. Experiences, thus, balance immediacy (sensing) with permanence (memory), bodily (emotional and physiological) with mental (sensemaking) operations, and passivity (undergoing) with activity (doing) (Jantzen, 2013). This balance characterizes the whole-body experiences that experientially oriented science centers are aiming at. In assessing the experiential quality of the exhibits, we, therefore, look at three parameters: 1) visitors' affective reactions to the exhibits' features (i.e., their "undergoing"); 2) visitors' interactions with the exhibits' features and with one another (i.e., their "doing"); and 3) visitors' sensemaking regarding which lessons for life in general can be distilled from these reactions and interactions (i.e., the visitors' learning). An analysis of how exhibit features and activities are experienced, thus, requires a framework that captures the dialectic relationship between the human body and mind on the one hand and exhibit features on the other hand.

Inspired by Jakobsson and Davidsson's (2012) sociocultural approach to study science centers, we used the concepts of mediated action and mediational means as the framework for our analysis of how exhibit features engage visitors and guide them in the transformation of experiences into knowledge. Mediational means can be defined as all possible and accessible resources in a learning process. Mediational means include *artifacts*, meaning resources of the physical world, for example, stones or cultural or historical products originating from human actions, for example, bicycles, pots, and games, and *human mediation* referring to interhuman actions, for example, collaborative activities, discussions, and combats (Wertsch 1998). In this perspective, the collaborative, whole-body activities (situated experiences) should be understood as mediated actions. Wartofsky (1979) has introduced a categorization to describe artifacts. He divided man-made artifacts into three hierarchical levels: primary, secondary, and tertiary artifacts. Primary artifacts are physical tools facilitating the performance of activities, for instance, a hammer, a lamp, or a ball. Primary artifacts correspond to Wertsch' physical world artifacts. Secondary artifacts are representations or modes of action created to govern our actions, for example, instructions, recipes, and maps. The third category refers to imaginary worlds and is a kind of extension of the secondary artifacts developing and mediating information about the secondary artifacts and their related actions, for example, a kitchen in which we use knife and recipes.

This framework was helpful in two ways. First, the framework helped us to identify and describe the exhibit features, for instance, in the PULSE Exhibition's Bike Shed the visitors settled on the bikes (primary artifact) to ride to the beach (tertiary artifact). They watched the video screen (primary artifact) where a video (secondary artifact) informed them where they should go and who were in front on the trail. Second, the theory on the mediated relationship between visitor practices and exhibit features helped us to understand how the visitors reacted to the exhibit features, structured their interactions, communicated with each other, and made sense of the features. The analysis allowed us to answer our research questions how the exhibit features guided the visitors to engage in and interact with the exhibits, and how they supported the visitors in transforming and making sense of their experiences. We used the gained insight to discuss how features could be improved to optimize the visitor experience.

RESEARCH DESIGN

Context

The study took place at a large science center in Copenhagen that emphasizes experimentation through interactive exhibits. The context was the PULSE exhibition consisting of eight individual exhibits, each of them consisting of multiple features to support visitor's experiential learning (Falk and Dierking, 2013). These eight exhibits were separate spaces for visitors to enter. Together they formed a square with a check-in and information point in the middle. The exhibits represented traditional parts of a family home and core family activities in Western societies, for example, a kitchen for cooking, a living room for watching television, a bathroom to be cleaned, and a field for playing a ball game together or a bike shed. The exhibition was, thus, a playful rendition of everyday chores.

The exhibition was to a large degree built on experiencing through physical tasks in whole-body, immersive exhibits with (intergenerational) collaboration as the prominent scaffolding feature. The visitors were encouraged to be physically active. They were, for instance, encouraged to crawl along the hallway, tilt family members off the living-room sofa, play "Earth is poisonous" in the kitchen, or dance in the bathroom. The exhibition's narrative focused on illustrating how families can easily do exercise and increase their heart rate while performing everyday family activities. Each exhibit revolved around one or several biological phenomena, for example, balance, coordination, speed, and suppleness, with the aim to show their importance for physical activity. The collaborative principle was reflected in tasks requiring cooperation, in games, and in the mandatory group formation at the check-in. The check-in took place at eight interactive welcome interfaces situated at the central square, the "Middle." During check-in, the group registered with a group name and an email address, and a site was created for each group to collect and store data about their activities. These data consisted of photos taken at each exhibit. After having checked in, the group could start its journey through the exhibition. The order of visits to the eight exhibits was random. Any order was allowed, but to start the activity all group members had to check in at the exhibit check-in stand. Operational instructions were provided by instruction labels appearing shortly as part of the exhibit check-in procedure both at the check-in devices and the wall screens. Scientific information about the biological phenomena of interest were primarily provided by quizzes and some few fast fact labels about the biological phenomenon of interest (e.g., about burning energy or on heart rate). The feedback labels with scores and fast fact labels appeared on separate screens placed in the exhibit rooms. Personal pilots were circulated in the exhibition sporadically with the main purpose of solving technical problems, for example, due to crash of screens and videos. For a video presentation of the exhibition, see Experimentarium (2021).

The eight exhibits consisted of a combination of mediated actions and primary, secondary, and tertiary artifacts (mediational means). The mediated actions consisted of tasks, for example, the task of switching off flashing lamps without touching the floor in the Balance Kitchen or biking as fast as possible to the beach in the Bike Shed. Each exhibit was composed of a room that the visitor entered, for example, a kitchen with pots and towels or a hallway with dropped coats, shoes, and school bags. Each room had a set of tools, a check-in device to register groups, and buttons to be pressed as part of the visitor activities. The *room*, its *artifacts*, and the *tools* constituted the primary artifacts. The labels and other guiding elements (e.g., sounds, music, and light bulbs) comprised the secondary artifacts instructing or supporting the activities. The *music* supported the dancing in the bathroom (or *sounds* the switched off lamps in the Balance Kitchen). A well-known *fictional character* was used to present the activities, for example, in the Dance Bathroom where the well-known children's TV star guided the visitors through the dancing task. *Labels* were used to instruct on how to carry out the activities, communicate scores, encourage the visitors, or inform about the scientific phenomena. *Videos* guided the visitors through the tasks in the Bathroom, Bike Shed, and the Fence Jump. The tertiary artifacts were built into the tasks providing a fictional *story*, for example, the child's play "the Earth is poisonous" in the Balance Kitchen and a *gaming element*, for example, competing with other groups in the number of switched off lamps without touching the floor or arriving in front of the others at the beach. The gaming dimension could be inter-group (e.g., which group earns most points in the Balance Kitchen) or intra-group (e.g., which group member is able to jump highest in the Fence Jump). The *fictional storyline* enchanted certain aspects of family life and its routine chores, for example, the Dance Bathroom or the Rodeo Lounge. In **Table 1**, we present the eight individual PULSE exhibits and their exhibit features.

Methods and Participants

Our study explored the visitors' experiences with the exhibition using data from walk-alongs (walking interviews) with 34 visitor groups comprising a total of 108 visitors (Kusenbach, 2003; Evans and Jones, 2011). Three external researchers carried out the ethnographic walk-along study over four months from November 2015 to March 2016 (Skov et al., 2019). All the walks were group walks. The units of analysis were 13 family groups (23 adults and 25 children) and 21 groups of primary school students (60 school children). **Table 2** provides an overview of the visitor groups.

The families were day-trippers that the researchers, working independently, contacted at one of the two entrances of the PULSE exhibition. When inviting the visitors to participate, the interviewers gave an oral presentation of the research project and handed out consent letters. As an incentive, the visitors who agreed to participate were offered free drinks in the café. The participants were told they were free to decide their pace and route through the special exhibition. The school groups were invited to the science center to enjoy a free visit and participate in the study. The groups were formed by the accompanying teachers. The students attended fourth and sixth grade in the Danish primary school system and were 9–10 and 11–12 years old, respectively. Consent letters describing the project and the walk-along method were signed beforehand by the parents of the invited school classes. The students were also offered free drinks in the café for their participation. While some participants explored all the exhibits, others only explored a few. The durations of the walk-alongs ranged from 10 to 72 min, with an average of 38 min.

Data Collection

The interviewers opened the walk-alongs with factual, demographic questions on the participant's age, nationality, motivations, and expectations, and whether she or he had a professional or layman relationship to health and physical activity. During the walk-alongs, the participants were stimulated to comment on their experiences and viewpoints on the exhibition. The interviewers used a short interview guide with three themes to inspire and prompt informal talks. These themes touched upon the visitors' perceptions, emotions, and engagement. The interviewers concluded the walk-alongs with follow-up questions on themes from the interview guide and issues that emerged during the walk-alongs.

TABLE 1 | Description and photo of the Middle and the eight Pulse exhibits.

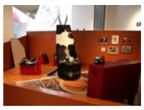
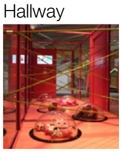
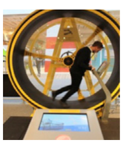
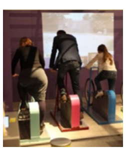
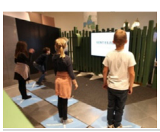
Exhibit	Interaction and features	Options for activity
The Middle 	Here, the visitors form groups and register by entering a group name. During their visit they can choose to watch photos taken during their activities, select photos to be sent to their email, and participate in a quiz where they get facts and information about key concepts.	• Allow the visitors to form groups and register by name and email. • Participate in the PULSE quizzes and gain medals. • Get facts and information about key concepts. For example heart rate, balance, and fitness. • Watch photos taken during their activities at the 8 exhibits. • Select photos to be sent to email.
The Balance Kitchen 	This exhibit builds on the "Earth is poisonous." Blinking buttons are placed at kitchen walls so the visitors must balance and climb the kitchen furniture to turn off the blinking buttons by touching then. They gain one point for each switched off button. If a member touches the ground all points are lost.	• Provide experience that you need a combination of balance, speed, and muscle strength to gain points. • Provide experience that you can play the "Earth is poisonous" everywhere.
The Rodeo Lounge 	This exhibit is inspired by the "wild bull" concept. In the lounge the visitors collaborate by pulling horse reins to kick off the group member sitting in the "best chair" in the living.	• Provide a task where the group members collaborate. • Provide a dialogue about the members' (bad) habits.
The Dance Bathroom 	The exhibit builds on a Wii Play. Here, the group members dance to disco music. A visual instructor guides them through cleaning movements and rates their effort. If they move insufficiently, they must repeat the cleaning moves.	• Provide that the whole group dance. • Provide the feeling how nice it is to move. • Provide experience that you can dance and have fun everywhere. • Provide the experience that dance challenges blood circulation, speed, and movement.
The Obstacle Hallway 	This exhibit is an obstacle race. Here, the visitors must crawl and fight their way through the stacks of shoes, jackets, and bags that have been dispersed in the hallway. They must all get through the hallway as quickly as possible to get the best time.	• Provide experience that you need balance and mobility to crawl and climb. • Provide experience that it is a fun and good exercise to crawl and climb. • Provide the experience that you can make crawling lanes everywhere.
The Energy Roller 	The Energy Roller is inspired by the "hamster wheel" concept. Here, one of the group members moves the roller—and earns kilojoules. It is tough, so they take turns. When they have sufficient kilojoules, they can buy carrots, chocolate, and Coca Cola in the visual super market. Carrots are healthy and therefor cheap while a Coca Cola is expensive.	• Show the relationship between physical activity (energy burning) and food energy (energy record). • Provide the experience of collaboration. • Provide coordination of physical activity.
The Bike Shed 	This exhibit is a bike race. Here the group members are invited on a bike trip to the beach. Who will be first to swim in the sea? When the members arrive at the beach, the handle of the bike measures their heart rate to see how quickly each member's pulse falls. For which member is most fit?	• Provide insight into heart rate—it increases with movement and decreases when we relax. • Provide insight into the concept of fitness. Some members have better fitness than others. • Provide an experience that biking is a good, everyday exercise.
The Fence Jump 	In the Fence Jump the group members are instructed to jump as high as possible. They get the chance to make two jumps. Both jumps are filmed, so the participants can see how and how high they jump at each try. Between the jumps they are instructed by video how to improve their jumping.	• Provide the experience that you need muscle strength, coordination, and technique to jump high. • Provide a shared experience that it is fun to jump. • Provide an opportunity to compete—who has the best jumping technique?
The Ball Cage 	Here there is a stall-tower with a hole in each seat that lights up in no particular order. Balls are continually jumping out from the two ends and you gain points by putting these into a lighting hole. In order to get as many point as possible within two minutes the members must collaborate and coordinate. The exhibit is inspired by hand ball and basketball.	• Provide an experience that ball games require precision, speed, strength, suppleness, and dexterity. • Provide the experience that ball games are both an informal activity and an organized, serious game. • Provide the insight that ball games also require collaboration and strategy.

TABLE 2 | Overview of composition of visitor groups.

Walk-along	Family groups	Walk-along	School groups	School
3	Two female friends visiting with their children. One mother with a pair of 7-year old twin boys and the other mother with one boy aged 7	1	Three boys (10, 10, 10)	A
4	Mother and daughter (11) visiting with mother's brother, his wife, and their baby	2	Three girls (10, 10, 10)	A
5	Mother and daughter (9)	9	Three boys (9, 9, 10)	B
6	Mother, father, son (14), and daughter (7)	10	Three girls (10, 9, 9)	B
7	Father with son (11) and male friend of son (12)	11	Two girls (9, 10) and two boys (9, 9)	B
8	Two female friends visiting with each one child: two girls (4 and 9)	12	Three girls (12, 12, 12)	A
14	Mother visiting with three children: two girls 9 and 16) and a boy (10)	13	Two boys (12, 12)	A
15	Two female friends visiting with each one child: two girls 4 and 9)	16	Three girls (10, 10, 10)	A
18	Mother and son (10) visiting with aunt	17	Two girls (10, 10)	A
19	Grandparents visiting with their grandchildren: two girls (5 and 13)	21	Two boys (10, 10) and one girl (10)	C
20	Two sisters (24 and 26) visiting with their younger cousin (12)	22	Two boys (10, 10) and one girl (10)	C
30	Mother with 3 sons	23	Three boys (12, 12, 12)	C
31	Mother, father and two daughters (no age indication)	24	Three boys (12, 12, 12)	A
		25	Three boys (12, 12, 12)	A
		26	Two boys (10, 10)	A
		27	Three boys (10, 10, 10)	A
		28	Three boys (10, 10, 10)	C
		29	Three boys (10, 10, 10)	C
		32	Two boys (9, 9) and one girl (9)	B
		33	Three girls (9, 9, 9)	B
		34	Three girls (9, 9, 9)	B
Total: 13 family groups with 22 adults and 25 children		Total: 21 school groups with 60 children		

The walk-alongs were tape-recorded by two wireless microphones, one placed on the researcher and the other on a member of the group, capturing the conversations, sounds, and noises in the exhibition hall. After the walk-alongs, the interviewers made structured notes on the route, speed, moods, interactions, collaboration, and conversation between group members.

The principal reason for choosing the walk-along method was that this method, originally developed in urban geography, allowed the researchers to accompany visitors on their natural outings, track their routes, and capture their immediate reactions, actions, and emotions in the instant of interacting with and experiencing the exhibits (Kusenbach 2003). Additionally, we chose the walk-along method with the purpose of combining the advantages of the walking interview with the classic sedentary interview. Studies by Evans and Jones (2011) showed that walk-along interviews triggered more location-specific data, whereas the classical interviews more often concerned more general topics like the neighborhood or issues related to the interviewee's life. At the end of the walks, we found a place in the periphery of the exhibition where we carried out the follow-up interviews, preferably sitting quietly with the visitor group.

Data Analysis

During the first step in the data analysis, the interviewers listened to the tape recordings several times to recall the walk and generate a list of emerging themes for each walk. The interviewers separately conducted this coding as an open, thematic analysis (Bryman, 2016). During the visitors' walks there were long breaks with no conversation between the group members (and the accompanying researcher) because the group was physically active and fully concentrated in solving the physical task, for example, alternately crawling through the hallway. Here, the sounds of visitors' gasping, moaning, and cheering are important in order to recall the emotions, efforts, enthusiasm, or exhaustion, which were part of the visitor's experience. By hearing audio recordings, each researcher revived and recalled the walk. Conversations among group members were transcribed. This first analysis resulted in an experience map that was prepared for each walk (Temkin 2010). The map consisted of the themes that emerged during the analysis and a textual description of the route of the visitors' journey, actions taken, conversations between group members, social interaction, and challenges in the visitor interaction. The map also included a list of the main experiences and moods that emerged during the analysis. By *main*, we mean the visitors' experiences and moods that stood out and by observation were most notable among the reactions to the exhibition. **Table 3** shows an example of an experience map.

The maps constituted a checklist in the later analysis where the researchers compared and discussed maps and coding results across the walk-along groups. To discuss results across the walk-along groups and determine recurrent themes paying particular attention to commonalities and differences within the study sample, the researchers applied a hermeneutic analysis strategy by relating parts from the observation notes, soundtracks, transcribed conversations, and experience maps to the whole visitor experience and vice versa (Schwartz-Shea and Yanow, 2012). The final analysis focused on the three types of artifacts functioning as mediational means (Wartofsky, 1979; Jakobsson

TABLE 3 | Experience map for walk-along 19.

Participants	**Walk-along 19** Family group 05.12.15 Marianne Lykke 4 visitors: grandmother (70), grandfather (68), girl (13), and girl (5) from Copenhagen area First visit to Plus.	**Visitor journey** The group does not discover the check-in. They walk around a bit perplexed and try in vain to get started. At the end I guide them to the check-in, and they register without problems. The eldest girl wants to start out with the Rodeo Lounge. There is a queue, and they decide to start with the Dance Bathroom. Here is also queue, and they line up. They use the waiting time to look at and learn from the other visitors. They comment on the active visitors. "Dammit she is good." "This is a bit youthful for us." The grandparents laugh disarmingly. "Can we do this?" The smaller child gets impatient. They have not noticed the timer, but use it at once when I tell them. "It will not take long." "Ok, are we all checking in?" When they are ready, the grandfather instructs. "Now we should prepare." "We must say on the spots." "Do as the girl." They laugh "Waw it has to be quick." Afterward they agree that it was fun. "It is built as a with play?" They all participate actively in the dance. They laugh and express that it is nice to move and loose breath. At the Rodeo Lounge the grandfather build up an atmosphere and read aloud the instructions. They have to check-in twice. The small girl will sit in the chair. She soon loses the patience and skip. The eldest girl takes over the chair, and the others makes ready at the "horses." They do not understand that they need to pull the rein. I have to explain what to do. "Ah it is us who need to move" They laugh. They do not see the instruction labels at the television screen. After they walk to the Energy Roller. They have to wait again ad use the time to watch and make a plan. The grandfather encourages the group. He uses the feature that they can "buy" a cola explains the feature. He keeps on the narrative. He encourages them to collaborate. "I need replacement". They work hard and help each other to keep the roller moving. They make turns. The grandparents help pushing the roller when the girls work. They do not discover that they can "buy" food. They find it very motivating that they can transform energy to food. They "buy" three colas with great pleasure. "We are very good." Then they try the bike shed. They have to wait and plan while they wait. They are all four active. The small girl cannot step the pedal. She cries and goes to her grandmother. The grandparent misses a real pedal, and they all miss a seat. They follow the instructions, and keep the hands on the handle. The grandfather comments that his fitness is bad. "Ah, my pulse is going down slowly." He comments on the technical and biological details. They do not visit more exhibits, because the small girl runs out of the exhibition. The others follow her "she is too small. This not for her."
Themes	**Instruction and preparation** The family oversaw at several occasions the instructive labels how to operate the features: check-in, Rodeo Lounge, Energy Roller. Further there were several instructions that they did not understand. They learned how to operate the features by looking at other groups while waiting. They also used the waiting time to plan their interaction. **Collaboration** The family collaborated in understanding and operating the features. **Roles** The children decided the route in the exhibition, while the adults had the coordinating role. The grandfather instructed the others and encouraged them when difficult or tough. The adults created team spirit by highlighting the qualifications of the participants. The eldest girl was also active in understanding how operate the features. **Dialogue sensemaking** The dialogue concerned exclusively how to operate the features. Only at the Bike Shed the grandfather commented on his fitness and how it is shown through the pulse. The comment did not trigger further discussion. **Experiences** Active participation, collaboration, interactivity, gaming element, and attention on fitness **Moods** Happiness, engagement, concentration, and patience	

and Davidsson, 2012), relating and exploring visitors' engagement, and sensemaking with the artifact types.

FINDINGS

The analysis of the data showed that six circumstances affected the ways in which the visitors engaged with and made sense of the exhibit features: 1) sensory attraction; 2) planned collaboration; 3) becoming (too) immersed; 4) commitment and perseverance through gaming; 5) child's plays as invisible instructors, and 6) situated scientific information. This section describes these circumstances as well as how the exhibit features functioned as mediated actions and mediational means for visitor engagement and sensemaking.

Sensory Attraction

The *scene* of the exhibition with eight individual exhibit *rooms*, each clearly defined by walls or fences and a specific color, had a strong visual effect, and attracted the incoming visitors' attention when approaching the exhibition. Particularly, the Rodeo Lounge and Energy Roller appeared to be both recognizable and interesting to the visitors. The visitors' reactions were generated by the combination of familiarity with the *stories* of rodeo riding and hamster wheeling and surprise with the different structure of the *actions*, for example, a rodeo with three horses and a bull in form of a chair, and a hamster wheel where it is the visitor who must do the running. Also, the *sounds* and the *human mediation* in the form of crowds and a hectic atmosphere with collaborating visitors shouting, laughing, hopping, and dancing drew attention and interest. The joyful pop *music* from the Dancing Bath and the visitors' cheering provided a welcoming and engaging atmosphere. Likewise, the physical *tasks* caught attention when entering the exhibition again, caused by this combination of familiarity with, for instance, ball games and bicycling and wondering what people were doing, because the activities were slightly different compared to the ordinary way in which these routines are performed. Contrary to the scene, story, and sound features, some of the tasks provided both positive and negative reactions; for instance, many boys felt shy about the task of dancing in the Dance Hall, and several adults were reluctant to participate in physically demanding activities. While some expressed worry ("Wow, this is difficult. Do you think that I can manage?", girl, 9 years, walk-along 5) others expressed great enthusiasm, for instance, when they realized that they were going to play ball in the Ball Cage. Only the combined check-in and information point in the middle of the exhibition did not attract attention. Its scenery of gray computer screens, the typing tasks, and the visitors' concentration and low speaking were not specifically interesting or striking. The findings tell us that sensory means have attraction power (Falk and Dierking 2013). Visitors were attracted by the inviting dancing music, laughing, and cheering people, and physical landmarks like the Hamster Wheel. Also, the child's play stories that provided a feeling of familiarity and nostalgic childhood memories had attraction power. It seemed that the tertiary artifacts in form of the very concrete and at the same time emotional child's play stories contributed better to attracting visitors compared to the other tertiary artifacts, such as, the fictional storyline in form of the family home, kitchen, bathroom, and the imaginary tasks of cleaning the bathroom and biking to the beach.

The *scene* of the exhibition with the eight shielded rooms caught the visitors' attention and made them curious to enter the rooms and discover what was going on. Similarly, the Rodeo Lounge and Energy Roller were visual landmarks standing out at the *scene.* Also, the *sounds* of pop music and countdown and the *human mediation* in the form of visitors shouting, cheering, and laughing drew attention and interest by sensory means. Summing up, the different examples illustrate the attraction power of sensory means.

Planned Collaboration

All the groups seemed to understand that the order of the exhibits was optional and random. The visitors chose strategically the exhibits they found interesting and planned their routes with regard to the crowds and waiting time, thus appreciating the open structure of the exhibition. Many groups used the timers on the local check-in screens to plan their route (e.g., "They have just started over there. This will finish soon. We'll start here" (girl 12 years, walk-along 12).

In line with previous studies, the (grand)parents took the role of facilitators in the family groups explaining what was going to happen (Blud, 1990; Sanford, Knutson and Crowley, 2007; Gutwill and Allen, 2010). They cheered on the children and ensured that they completed the activities. In most school groups, the children acted on equal terms, and altogether helped each other to understand the activities, cheered at and encouraged each other. As seen in the studies by Skydsgaard, Andersen and King (2016), they discussed and shared their feelings and thoughts. In family groups, the members explicitly divided the tasks among one another; in most school groups the cooperation was intuitive and tacit. In both these types of visitor groups members took turns, for instance, in the physically demanding Energy Roller.

Both family and school groups highlighted the joint activities and emphasized in the post interviews that the need for collaboration and coordination was an important feature of the visit confirming that museum visits are motivated by a combination of social, recreational, and learning reasons (Falk and Dierking 2013). The social interaction did not only happen within a group. The groups also helped each other, mostly with advice on how to operate the interactive features or how to gain better scores.

Becoming (Too) Immersed

Most visitors were very concentrated on planning and carrying out the physical activity. They barely had time or cognitive resources to talk about the scientific topics. So, in general the groups did not take the time to talk together, read the few explanatory exhibit labels, or take the quizzes. Only three groups out of the thirty four went back to the Middle to answer quizzes related to the exhibits. Eight groups used the opportunity to collect photos. The findings match findings from Dancstep et al. (2015) that whole-body interactive exhibits have a diminished intellectual engagement compared to hands-on exhibits that also held the visitors' attention for a longer period. The family groups did not discuss the exhibit themes more often or more comprehensively compared to the school groups, contrary to findings by Crowley et al. (2001). Actually, it appeared from the conversations and the follow-up interviews that as the school children had been introduced to the overall exhibition theme before the visit, they paid attention to the scientific themes of the exhibition.

The findings showed that the whole-body activities that required both physical as well as social coordination and concentration took the visitors' full attention. The visitors were completely absorbed in jointly understanding and coordinating the activities so that they could complete the *activities* and *games*. The exhibition's goal of physically engaging and motivating the visitors to physical activity was fully achieved, while the physical activity at the same time was an obstacle to the exhibition's second goal of getting visitors to reflect on and talk about the importance of physical activity for their health and well-being. Correspondingly, the free order of activities had a motivating effect, just as the free order at the same time required planning and took the visitors' attention.

Commitment and Perseverance Through Gaming

Some groups took up the gaming element of the activities ("Hurry up! There is a ball. We got 30 points", boy, 9 years, walk-along 9). Other groups saw them as play ("this is fun. You are not allowed to touch the ground. You must run around and press a lot of buttons. And if you touch the ground, you must start all over again", boy, 9 years, walk-along 11). Some groups barely noticed the scores and points. In general, family as well as school visitors found point scoring to be engaging and fun, but very few saw competitions as a motivating feature in itself. When asked in the post interview, a schoolboy explained: "Of course, we check how many points the other groups get. We were better than the girls at the Dance Bath, haha. What I like most is when it is the team that must do well" (Boy, 10 years, walk-along 1).

While the competitive element of comparing points across visitor groups did not motivate or stimulate visitor interaction, the points stimulated the visitors to try out the activities a second time to improve their results. As such, the *gaming* feature and points had the important role of motivating repeat interaction, increasing holding time, and intuitively and unconsciously engage the visitors to work with their physical techniques and collaborative coordination.

Child's Plays as Invisible Instructors

The activities were intuitively understandable for the visitors. The *tasks* themselves were simple and clear, for example, turn off lights, dance, and put balls in a hole. This understanding was furthermore well supported by *child's plays* that provided an immediate understanding of how to interact by activating previous experiences. In the Ball Cage, knowledge of ball games and scoring guided the visitors to throw the ball into the goal to gain points. In the Fence Jump, the visitors were guided by their knowledge of play in for example, school yards or gardens. Likewise, in the Dance Bathroom, the visitors were guided by the Wii Play in form of the instructing video and the story that we sing and dance in the bathroom. The understanding was also supported by a clear relationship between the *task* and the *game*, for example, between switching off blinking lamps and earning points. The child play "Earth is poisonous" supported the understanding that the visitors should balance the kitchen equipment to fulfill tasks and dramatized the game by introducing the rule that you lose all points if you touch the floor. In these exhibits, the visitors' interaction was supported by a clear relation between the task, game, and story.

In contrast, the visitors had problems in understanding the interaction in the Rodeo Lounge, Obstacle Hall, and Bike Shed due to unclear relationship between the task, story, and game. They did not grasp the more contrived stories, for example, in the Rodeo Lounge where group members had to kick one of their companions away from the sofa and the television set to get the person concerned to exercise instead. Similarly, in the Obstacle Hallway the relationship between task and game was unclear. In the Obstacle Hallway, the visitors did not understand either the task or the relationship between the task and the game. The visitors were not sure whether the aim was to traverse the hall as fast as possible or to avoid touching the rebound. In addition, they did not grasp whether they gained points individually or as a group. Also, in the Rodeo Lounge, the task caused divergences as the visitors did not realize that they needed to pull the interactive reins to kick off the person in the chair. Also, here the mismatch occurred because the relationship between the task and the game was unclear for the visitors. In the Energy Roller, the visitors in general understood the task of running the wheel to "earn" kilojoules as a token of the amount of energy burned. The aim of the story was to raise the visitors' awareness of differences in kilojoules between various types of snacks, for example, carrots or chocolate bars. Running the wheel was a physically quite demanding activity apparently motivating many visitors to attempt to earn points for "buying" the more "expensive" rewards (e.g., a chocolate bar which cost more kilojoules than the carrot). In this respect, the game came to contradict the story. In a similar vein, many visitors did not see the relation between the story and the game in the Bike Shed. The task in this exhibit was to bike on a home trainer and the story (supported by a video) was to try to be the first to reach the beach by bike. The game, though, was about who was able to decrease her or his pulse most significantly after having reached the beach. During the countdown the visitors had to hold their hands on the handles to see how the pulse decreased. Many visitors overlooked this aspect and left the exhibit before the countdown was over and the game had ended. In this the story contradicted the game. In all, the findings show how the child's play intuitively guided the visitors' understanding of the exhibits leveraging the visitors understanding of the task and the game.

Situated Scientific Scaffolding

Only a few groups seemed to perceive and reflect on the biological phenomena presented in the exhibits, for instance, the importance of balance and mobility in the Balance Kitchen and the Dance Bathroom. An example is how the mother and daughter in walk-along 5 reflect and talk about pulse:

"Keep the hands at the handle. So … as quick as your pulse falls …. You can see your pulse down there. It is 134, right?" (mother).

"Is it very high?" (girl, 9 years).

"Yes, but you are a child. It should actually register that you are a child and I am a grown-up" (mother).

[Bell rings and the pulse measurement is completed].

"Ok, my pulse decreases with 53 beats while I was relaxing. Yours only decreases 20." (mother).

"Aha" (girl, 9 years).

"So, in theory, it should mean that I am in a better condition compared to you, but I do not think so" (mother).

In the Energy Roller some visitors used the possibility to transform the earned kilojoules into food, but none of them talked about the relationship between energy intake and energy burning for keeping, gaining, or losing weight. The groups talked about their (lack of) fitness in the Bike Shed. For instance, the following dialogue occurred during walk-along 8:

"Man, it is hard. Wow, mine is high—see my pulse" (mother).

"My heart is beating like hell" (boy, 10 years).

"My legs are trembling" (girl, 10 years).

However, only a few considered the importance of the heart rate and how we can use it to measure fitness by how quickly one restitutes after intense activity. Generally, the exhibition was not successful in stimulating recognition and conversation among the visitors about the importance of specifics of physical activity, for example, heart rate, burning energy, and muscle strength. The collaborative planning and degree of whole-body interaction took the visitors' attention. Only in the Fence Jump the integrated video instructions (a secondary artifact) on how to improve jumping techniques stimulated visitor conversations about the biological phenomena. Here, the video that guided the visitors through the jumping and provided hints on how to jump higher was successful, because the mediation and explanations appeared as part of the activity, giving the visitor time to read and reflect. Consequently, many group members started encouraging one another to improve their jump by utilizing their body more efficiently.

DISCUSSION AND IMPLICATIONS

We started our analysis by asking how exhibit features supported the informal, experiential visitor learning in a whole-body, collaborative science exhibit and which features could be improved.

Our findings point at three issues to consider in exhibit design. We use the three parameters of experiential learning derived from Dewey (2008a) and Jantzen (2013) to structure the analysis into how the visitors engaged with the exhibit features, how the visitors' *reacted* physiologically and emotionally to the features, and how they were motivated to *interact* cognitively with these means and actions and hereby explore the exhibit topics. Next, we analyze how the visitors *made sense* of their engagement with the exhibit features. In the analysis we use the Wertsch (1998) framework of mediated actions and mediational means (physical artifacts and human mediation) and Wartofsky's categorization and primary, secondary, and tertiary artifacts to guide the analysis.

First, we must emphasize that togetherness, the need for collaboration and coordination, and the shared physical activities were key motivations for visiting the exhibition. A mother in a family group explained "It is the social experience with our family that is central, not the learning. The exhibition is perfect because it is neither easy nor difficult, and it is good that you can try some things to increase your heartbeat" (Mother, Walk-along 6). At the same time both types of visitor groups emphasized the learning elements during the post-interviews and were very clear what they had learned from the exhibition, that is, "It is harder to exercise than I thought. You need both balance and to think quickly" (Boy, 10 years, walk-along 9) and "You must exercise. You must stick together. You need to collaborate in the Ball Cage" (Girl, 9 years, walk-along 11). This is in line with a previous research that science center visitors emphasize social interaction as a key motivation (Falk and Dierking, 2013). However, compared to previous studies, the visitors placed extra emphasis on the fact that most exhibits required a high degree of teamwork to function optimally. The need of strategic coordination and cooperation were of great importance to the visitors.

As for the wish to engage visitors and make them react physiologically and emotionally, the data gathered through observations during the walk-alongs showed that visible landmarks, inviting dance music and other sounds, recognizable play activities, and human mediation in form of high-spirited collaboration were able to catch the visitors' attention and generate a diverse set of reactions, physiologically (enthusiasm and arousal) as well as emotionally (enjoyment and anxiety). Both happy and anxious expectations engaged and drew the visitors to the exhibits. The findings suggest that the sensory means captured the visitors' curiosity intrinsically and motivated visitors to approach the exhibition (Csikszentmihalyi and Hermanson, 1995).

Concerning experiential interaction and exploration, the clear tasks and close relationship to games and the well-known script of child's plays (i.e., the stories) were successful in activating the visitors. The combination of physical activity, gaming, and recognizable stories provided engagement as well as structure to the task and served, hereby, as cognitive guidance in how to interact with the primary artifacts and carry out the tasks. The findings further showed the need for a conceptual coherence between the task, game, and story. The illogical relationship between the game and the story in the Energy Roller and in the Bike Shed and between the story and the task in the Rodeo Lounge and the Obstacle Hall generated interaction problems. In these cases the connection between primary and secondary artifacts on the one hand and tertiary artifacts (the game script and story world) on the other hand was unclear (Wartofsky 1979). These mismatches caused not only confusion but also made visitors miss important aspects of the exhibition's intentions. These findings confirm previous research that storytelling and narrative are important guiding design principles (Murmann and Avraamidou 2014; Skydsgaard, Andersen and King 2016) and are also in line with the Shaby et al. (2017) point that recognizability and guidance through well-established scripts are essential for intuitive, uncomplicated interaction and exploration. However, the findings also stress the importance of close relationship and coherence between the different exhibit features, hereby supporting Allen (2004) notions of conceptual coherence and immediate apprehendability. The visitors understood the purpose of the interactions immediately due to the well-known child's play, but they did not recognize the intended themes when there were no clear, precise relationship and conceptual coherence between the multiple features.

The child's play as tertiary artifacts increased the engagement by moving the actions away from the school's formal learning setting to informal leisure and play. The playful approach further meant that the game's point scores were primarily used as an intrinsic motivation within the visitor group to try the activity once more to see if they could improve their effort and scores. Hereby, the extension and transformation of the task into play and the game stimulated the visitors to work with and improve their physical techniques and coordination in the group.

When it comes to *sensemaking*, the analysis showed that, due to the physically demanding activities and the required social collaboration, the visitors were not able to engage in in-depth discussions of the exhibition's scientific themes. In most cases the awareness of the significance of physical ability and coordination was unspoken between the participants, but it was clear through walk-along observations and some few visitor conversations that the participants sought to learn from their whole-body experiences and tried to improve their physical activity when trying out the exhibit task a second time. The findings are indications of situations in which visitors learned by relating bodily to the physical phenomena by physically trying out and improving their movements and coordination and hereby recognizing the importance of leg position for a good starting point for a jump in the Fence Jump. As such, the findings support the general believe that immersive, whole-body experience may be capable of enhancing visitor learning (Wellington, 1998; Gilbert, 2002). As in Dancstep et al. (2015), only few visitors expressed their reasoning verbally, but they showed their sensemaking when trying to improve their jumping techniques. Yet again, these findings demonstrate the importance of a conceptually coherent exhibit design with clear connection between lines of reasoning, for example, you can jump higher if you combine coordination and muscle strength (Allen 2004).

In several of the exhibits the supporting instruction and scientific information were incorporated into the activity. This worked especially well in the Fence Jump and Dance Bathroom, where the instructions on how to use the body to jump or dance were integrated naturally into the interaction by video films. In between the jumps and dance exercises a small video instructed how the visitors coordinating their movements can use their muscles more efficiently. In the Dance Bathroom the instructions were conveyed by a human mediator, a well-known children's TV character, that instructed the visitors by showing and explaining the movements. In the Fence Jump the instructions were made by a combination of textual guidelines and photos of a mother showing the movements to improve the jump. The findings tell us that integration of instructing labels that inform about the scientific subjects (secondary artifacts in Wartofsky's categorization (1979)) into the interactive process could be one way to support the visitors' understanding and sensemaking. Science centers have long relied on human mediation and informal docents to help guide visitors' experimentation (Gutwill and Allen, 2010). These findings indicate that future studies should focus on examining in detail the effect of video instructions integrated into the experience and how to convey these instructions, that is, by video films or textual and graphical means. Another solution to support the visitors' conversations and exploration of the scientific topics, in line with previous research, may be to integrate question labels or quizzes as interactive labels inviting the visitors with question-and-answer options, and to add a label at the entrance of the exhibition introducing the big idea, that is, a clear statement stressing what the exhibition is basically about (Gutwill and Allen 2010; Serrell 2015). A third solution could be to provide access to the quizzes in the email with selected photos that is sent to the visitors after the visit, as the visitors may have better time and cognitive surplus after the visit to talk with one another about the experience and the scientific topics. With this solution, it is considered that the visitor's experience consists of two temporal dimensions (Dewey 2008b; Jantzen et al., 2011). First, the visitor interacts with exhibits and has an experience, and then the visitor assimilates the experience, whereby previous experiences are affected. When we send the quizzes and pictures to the visitors after the visit, we seek to extend the visitors' inquiry and sensemaking by providing time for reflection and new questions, and for production of new ideas and knowledge (Ansbacher, 1998). Post-interviews by Lykke and Skov (2020) with family visitors three month after a visit to an interactive science exhibition showed that the interviewed families could retell the visit in detail, just as they told how they had tried similar activities and learned about similar topics after the visit, at home as well as at other science centers. The post interviews also showed that the degree of understanding and learning differed and depended on previous experience, knowledge, and interest.

The results point to the following principles for designing interactive, whole-body exhibits: 1). sensory features to catch visitor attention and provide positive expectations, 2) a coherent combination of the task, game and story to engage and leverage the interaction, and 3) integrated instruction and scientific information to diminish the cognitive load and scaffold the experiential learning.

CONCLUSION

We examined two questions about whole-body, collaborative exhibit features: 1) which features contributed to engage the visitors in exploration of the exhibition topics and 2) how the exhibit features guided visitors to make sense and transform their experiences into knowledge. Our aim was to increase knowledge about exhibit features and how they support the visitor learning.

The PULSE exhibition was developed to encourage visitors to try out ways of being active. The purpose was to provide the visitors with an opportunity to discover that physical activity is important and fun for everybody and possible to carry out in everyday life. We used the framework of mediational means and mediated actions to understand the visitor experience as dynamic interactions between visitors and exhibit features (mediated means), between group members internally, and between different groups visiting the exhibition (human mediation). The three parameters in experiential learning were used to guide the analysis: reaction, interaction, and sensemaking.

The findings confirmed togetherness, collaboration, and social interaction as a key motivation for the science center visit. However, compared to previous research, the visitors placed extra emphasis on the need for teamwork, strategic coordination, and cooperation due to the use of child's plays and games as mediational means. It was not only the togetherness and collaboration that was important but also the fact that the tasks required strategic consideration and joint coordination to be solved optimally. The playing elements were attractive and motivating due to playfulness and gaming elements, but they also fulfilled their means as tertiary artifacts developing information to the visitors and supporting their sensemaking process.

Regarding individual exhibit features the visitors reacted to the sensory features and were attracted by the scenery, the sounds, cheering visitors, recognizable activities, and child's play stories and games. The physical activities and the gaming elements in the individual exhibits created an atmosphere of joy and engagement supporting visitor interaction. In some exhibits there were contradictions or mismatches between the task, the game, and the story causing misunderstanding and frustration. A close relation between the task and the game supported by scaffolding in form of clear, recognizable stories, and well-connected, coherent lines of reasoning is essential for visitor interaction. The games had a positive effect on the holding time because the visitors wanted to try out the activity a second time to see whether they could improve their scores and physical techniques.

In general, the exhibition design proved to be very successful at engaging the visitors in physical activity and providing the visitors with the insight that physical activity and collaboration is fun and important. Concerning insight into the biological phenomena, only a few visitors talked about the scientific topics, that is, how to exercise and how to improve their muscle strength, heart rate, and balance in everyday life. Visitor conversation primarily concerned practicalities and the physical effort. However, some sensemaking could be observed when the visitors tacitly during their activities tried to improve their movement, either by simply trying out a new physical technique from their own experience or by following instructions from the exhibition labels. In few cases the visitors shared experiences on doing the activities.

The findings are derived from participatory observation and informal talks with the visitors during the walk-alongs and from post-interviews. Both the observation of the visitors' interactions with the exhibits and their emotional response to activities and artifacts provided a good basis for understanding the visitors' engagement and sensemaking. In particular, listening to sound recordings made it possible to document and maintain the researcher's insight into and understanding of the visitors' experiences. However, the high level of activity also affected the researcher's ability to both capture details as well as retain them, which is a challenge with the walk-along method. The post-interviews were valuable to follow up and get further details. At the same time, it is important to emphasize that the visitors are invited for post-reflection and that their answers and stories are not spontaneous reflections, but elicited reflections. In all, these are the methodological limitations of the study. Further, it is important to stress that the findings represent the family or school group as a unit and not specifically the individual children in the unit.

The study supported previous findings that interactive, whole-body exhibits are engaging and enjoyable leading to high visitor interaction (Allen, 2004; Gutwill and Allen, 2010). The study also confirmed findings that interactive, whole-body exhibits are less effective at fostering content-related conversations and reasoning (Dancstep et al., 2015). In return and in contrast to previous studies about holding time the study showed how gaming elements helped to retain visitors who took several trips to improve their scores and hereby work with their physical techniques and collaborative coordination of the task. Well-known child's plays served as motivating narratives and scripts for the whole-body activities. Redesign should concentrate on improving the scaffolding of verbal intragroup discussions and critical, inventive reflection and sensemaking by integrated, dialogue-inviting secondary artifacts, for example, videos, labels, and intuitive, clear-cut lines of reasoning.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Etisk Råd, Det Humanistiske Fakultet, Aalborg Universitet. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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A Framework for Understanding the Nature of Questions Asked by Audience Participants at Science Cafés

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Science Cafés are events designed as public engagement tools that create the opportunity for open dialogue between members of the general public and experts on the issue being discussed at the event. This study explores the nature of questions being asked by audience participants during discussion sessions of Science Café events. It was conducted by coding audio recordings of audience participant engagements at 41 Science Café events held between 2010 and 2019. The result of this analysis produced a novel taxonomic framework to describe audience participant behaviors in terms of their learning goals. This framework was evaluated by applying it to samples of Science Café question data selected by Science Café topic theme. Comparisons between question-asking behaviors for specific Science Café topics and overall trends in question-asking behaviors for all Science Cafés revealed significant changes in audience participant learning goals when asking questions at Science Cafés centered on different topic types. Implications for understanding Science Café audiences and potential developments for Science Café events as public science engagement tools are discussed.

Keywords: science communication, dialogue, public engagement, informal learning, question asking, science café

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INTRODUCTION

Science Cafés are events designed as public engagement tools that create the opportunity for open dialogue between members of the general public and experts on the issue being discussed at the event. Audience participants have the opportunity to direct questions or commentary to the panel and/or other event attendees during the discussion period of the event, which are then discussed by the panel and/or other audience members. To date, there has been little exploration of the nature of questions put forward for discussion at Science Café events. This study clarifies the nature of questions asked by audience participants at Science Café discussions in terms of the learning goals of those participants, with the aim of understanding the types of information being sought or exchanged by Science Café participants.

BACKGROUND

Science Cafés as Sites for Dialogue

The value of engaging public audiences and experts in two-way (dialogic) discussions about science topics has been well documented (Boyette & Ramsey, 2019; Mejlgaard, 2009; Davies et al., 2009; Kerr et al., 2007; Lehr et al., 2007; Zorn et al., 2012). Success may vary depending on the format in which dialogue takes place between these two groups, but generally speaking, participation in dialogue results in positive attitudinal shifts and a potential convergence of attitudes between public audiences and experts (Zorn et al., 2012). In the same vein, audience members participating in dialogic discussions in educational settings benefit in terms of content comprehension whether they are participating directly in the dialogue, or if they are witnessing the dialogue as a passive participant (as opposed to being the recipient of information delivered in a strictly transmission model fashion) (Craig et al., 2000).

Rowe and Frewer (2005) catalogued three mechanisms for public engagement on the basis of flow of information. Of special interest is the "public participation" tier, also labeled "dialogue events," by which information flows in both directions between the public and the event representatives. Dialogue events serve as ideal scaffolding for social learning (Davies et al., 2009). Sociocultural and social constructivist theories for learning dictate that learning can be promoted in social contexts, for example in dialogue between individuals of different levels of expertise on a topic (Hodson & Hodson, 1998). Bonk Jay and Kim, 1998 extend sociocultural theory to adult learning to suggest that "adult learning is enriched in collaborative and interactive learning communities with small-group discussion [...] candid conversation, social interaction, and reflection" (p.76).

Science Cafés are live public events intended for open conversation between scientists and public audiences about a determined science topic (Dallas, 1999). These events are meant to be relaxed, open, and entertaining forums, unconnected to informing policy. Prior knowledge of the science topic being discussed is not required to attend—the events are meant to be open to any member of the public, although some venue settings (i.e., bars) might restrict "any member of the public" to mean adults of legal drinking age. These events are typically held in non-academic settings. Science Cafés were first established in the United Kingdom as "a place where, for the price of a cup of coffee or a glass of wine, anyone can meet to discuss the latest ideas of science that are impacting society" (Dallas, 2006). At present, there are many variations on the Science Café format, but they typically include live presentations by expert panelists (without the use of visual aids), followed by a break and a discussion period wherein audience members might ask questions of the panelists or contribute their own knowledge or opinions to the discussion. Because the flow of information at Science Café events are intended to be in both directions between audience participants and panelists, discussion might equally focus around the importance of the issues being discussed as much as the content of the issues themselves, meaning that there is no singular goal of the discussion (e.g., expert teaching layperson with the singular goal of increasing layperson's understanding) (Davies et al., 2009). The dialogue format of the discussion period supports a social constructivist model by encouraging Science Café participants to move beyond the transmission model structure of the expert presentations and interact with the panel experts to not only facilitate their own understanding of a topic of discussion, but also to empower them to integrate their own knowledge, experiences, and perspectives into the exchange of information (Driver, 1997; Hodson & Hodson, 1998; Davies et al., 2009).

This study uses data gathered from Science Cafés held by Science North, a science center in Sudbury, Ontario, Canada. Science North's model for Science Cafés holds consistent to the structure of panelist presentations to introduce the event's topic during the first half of the event, followed by a break and a moderated discussion period where audience participants are encouraged to approach a microphone to ask questions or contribute impressions, or to submit written questions *via* slips of paper or Twitter posts for the moderator to read as a proxy. With few exceptions, Science North did not hold their events at the science center; rather, as a goal for accessibility to a wider public audience, these events were held at local restaurant and bar venues in or near the city's downtown core. To further promote this accessibility, these events were free and unticketed, and the event venues were not closed to non-participant consumers. The audiences tend to consist primarily of members of the public who are already interested in the event's topic or who are seeking to deepen their knowledge of said topic; however, due to the usually free and public nature of Science Cafés, the event has the opportunity capture new audiences who have gathered at the venue for other reasons (McCallie et al., 2009).

As events, Science Cafés are structured with the intent that public audiences will engage in dialogue with the panelists and share their personal viewpoints, and that this discourse might be empowering as it removes barriers between public audiences and academic panelists (Powell and Lee Kleinman, 2008; Dijkstra and Gutteling, 2012).

There is a breadth of literature taking both quantitative and qualitative approaches to understanding why Science Café participants attend the events and how they feel about the events (Davies et al., 2009; Navid and Einsiedel, 2012; Dijkstra, 2017) and audience self-positioning as experts or non-experts in conversation with invited experts (Kerr et al., 2007); however, there is little research into understanding the nature of the questions that public audiences ask when they join the discussion at Science Cafés. In general, there is a gap in current literature with regards to public audiences at events that do not inform policy (Davies et al., 2009; Dijkstra, 2017). Studying the nature of questions being asked at these types of events can provide insights to audience participants' motivations and/or learning goals that led them to ask these questions. Studying the nature of questions being asked at Science Café events will be useful for science communicators to design events that support the interaction between event attendees' interests and goals and the information provided by the panelists. This understanding of the nature of questions can likewise be useful to scientists seeking to engage public audiences with information at informal dialogue events. The popularity of Science Café events worldwide has shown that audiences are interested in learning at these events and engaging with the science discussions being presented (Norton and Kohara, 2009). Understanding the nature of the questions being asked by these attendees will provide insight into the motivations behind the desire to learn at these events. If we put our audiences in situations that align with their motivations, their attention will be better focused on relevant information because they want to learn (Ram, 1991).

Question-asking in the Context of Science Cafés

Questions are expressions of learning goals, and they are often posed when the question-asker identifies a gap in their model or understanding of a topic or issue; asking the question is an act that seeks to acquire information that will correct that gap or update their understanding (Ram, 1991; Graesser and McMahen, 1993). In terms of questions as tools for learning science, (Chin and Osborne, 2008) further elaborate that "questions have the potential to *1*) direct [students'] learning and drive knowledge construction; *2*) foster discussion and debate, thereby enhancing the quality of discourse and classroom talk; *3*) help them to self-evaluate and monitor their understand; and *4*) increase their motivation and interest in a topic by arousing their epistemic curiosity" (p.3). From a social-cognitive perspective, Science Cafés are positioned to engender discussion and a similar array of learning goals to those identified by Chin and Osbourne, goals that are broader than simply "filling a gap." While earlier observational classroom studies have cited that students ask few questions, and seldom ask "high quality" questions that foster discussion (Dillon, 1998; Graesser and Person, 1994; Graesser and Olde, 2003; Carr, 1998), Science Café events differ from classroom settings in that the participants have self-selected to participate in the discussion event and have been encouraged by the format of the event to ask questions and participate in discourse. The structure and philosophy of Science Café events align with social constructivist approaches to learning in that audience participants act as social peers whose conversation allows them to co-construct knowledge and engage in meaning making (Vygotsky, 1978; Chin, Brown & Bruce, 2002; Alexander, 2005). Finally, the open-forum structure of Science Café discussions allows for participants to explore avenues that are of individual interest to them. In a study of Grade 6 students, Chin and Kayalvizhi (2005) found that students preferred investigating questions that they constructed themselves rather than investigating the questions provided to them by a teacher or texts and that these students reported positive feelings of fun, excitement, or happiness toward the experience of investigating their own questions. By extending Chin and Kayalvizhi's findings to adult learners participating at Science Café events, understanding the natures of the questions that these participants choose to pose and investigate with event panelists will also help us understand what these question askers find interesting or exciting about the event topics.

Question generation processes, and what makes a "good" question has been studied in depth in classroom settings (Graesser and Person, 1994; Bransford et al., 1985; Ciardiello, 1998; Arbreton, 1998; Graesser and Olde, 2003). Working definitions of what makes a "good question" in classroom contexts often refers to the incorporation of cognitive processes such as memory, convergence, divergence, and evaluation (Ciardiello, 1998). The rhetoric of qualifying questions as "good" or "poor" indicators of comprehension is less useful in the context of audience participants who ask questions at Science Cafés and similarly structured informal adult learning events. Instead, the aim of this study is to articulate the nature of the questions being asked in terms of learning objectives that motivate their asking and to investigate motivations that do not necessarily prioritize topic comprehension. A question that may not be a "good" question in the context of clarifying a task or factual knowledge in a classroom setting can still meet a learner's goal of updating their model of understanding in the context of a Science Café. The goal of a Science Café event is not typically structured such that participants will walk away from the event with expert knowledge on the events' topic; the learning goal(s) of Science Cafés are largely determined by individual audience participants, and shaped by audience-panelist interactions.

Ram (1991)'s goal-based model for learning raised two issues: one of content (*What kinds of questions are there? How does the question-asker know which questions to ask?)*, and one of process (*What difference do questions make? What effect do they have on the understanding process? How do they affect what one learns? How are questions managed in memory?)* In addressing the nature of questions, in terms of learning goals, to discuss the issues of content, Ram built a computer model of question-asking with respect to seeking knowledge from textual information. His model, which required an in-depth development of theory of questions and question asking, was largely based on learning goals articulated by Ng and Bereiter (1991). Ng and Bereiter (1991) posited three levels of goal orientation in students: *1*) task-completion goals; *2*) instructional goals; and *3*) knowledge-building goals. This study is also concerned with questions of content, but will need to create a new model that satisfies the nature of questions within the context of askers seeking information from live panelists at an informal learning event (specifically Science Cafés). Since audience participants at Science Cafés are not being directed to complete tasks and are not receiving instructions as students would in a formal classroom setting, Ng and Bereiter's model and similar models intended for evaluation the natures of questions or learning goals in classroom settings are not applicable in unadapted forms to Science Café contexts. This study proposes a new model, based on the nature of questions asked by Science Café participants, that can be used to represent the learning goals of audiences who attend informal panel discussions that do not inform policy.

As environments for learning, Science Cafés prime audiences to ask questions in ways that differ from formal classroom settings. Participants attending Science Café events do so with the shared expectation that they will have access to the panelists as knowledge sources, and that the event is intended to be a platform for discussion (and introductions to the event reinforce these expectations for participants). Sociocultural theory (Vygotsky, 1978) recommends examining the social interactions and social contexts with which classroom learning occurs. In terms of adult learning in informal contexts, we can look toward the co-construction of knowledge among peer groups, and in the case of Science Cafés, as social peers who are attending the events together, or as a larger audience peer group. Similarly, a social constructivist approach implies that motivation and interest in learning (including cognitive and affective engagement) is tied to the context of the social learning environment. Audiences attending Science Café events are doing so to learn in an informal social environment among peers and to access perspectives that they would not be able to access in a non-social (e.g., individual) context. Unlike a transmission-type presentation, social learning environments that encourage question-asking and dialogue can introduce alternative perspectives and new knowledge to all participants, including the expert panelists (Nussbaum, 2003). Earlier studies have provided evidence that students, when engaged in discussion, tend to incorporate one another's arguments and use them themselves (Anderson et al., 2001; Kim et al., 2007).

The nature of questions asked by public audiences are equally as informative as the answers provided by the experts being questioned in that the questions reveal the intent (information-seeking, communication of realities, preoccupations, or desires, or other) of the individual posing it (Derr, 1984; Uwajeh, 1996). By identifying emergent patterns in the natures of questions being asked by Science Café participants we will be able to better understand how public audiences question expert panels in this type of public forum and trends in question-asking behaviors. This understanding might allow us to extrapolate to audiences who do not access Science Café events and suggest approaches for public communication around challenging or controversial science topics—topics typically "up for debate" at Science Café events.

For example, in their study to both understand science café participants' views of synthetic biotechnologies and evaluate the Science Café as a forum for science communication on this specific topic, Navid and Einsiedel (2012) analyzed 28 questions from four of the five Science Cafés held in a synthetic biotechnology series and identified three themes that featured strongly at almost all of their events. These question themes were specific to the topic of synthetic biology:

1) What is synthetic biology? Is it really just genetic engineering?
2) How long will synthetic biology really take? Is it held up by research or by technology?
3) How transferable is synthetic biology technology especially for developing countries? (p.7)

Other questions raised involved concerns about environmental safety, especially in the event of an unintentional release, while others expressed worries about human safety and biosecurity. Dijkstra (2017) reviewed Science Café audience questions as evidence of audience interest and captured questions on the topic of nanotechnology: audience members asked "[...] questions about society-related topics, such as risks and benefits, ethical issues, possible fear for a new technology but, at the same time, they asked questions for clarification of the various issues that were brought up by the speakers" (p.7). Neither study provided much discussion about these audience questions nor the thematic patterns that emerge. As well, these example studies focus on audience participation in the framework of select topics (synthetic biotechnology and nanotechnology, respectively) because the goals of these types of studies tend toward identifying trends and measures in audience attitudes towards those topics of interest, given that popular topics for Science Cafés are selected on the basis that they might be controversial or in debate stages in terms of public understanding or reporting.

There is a gap in comparing audience questioning behavior across a range of topics. Is there a trend in dialogue behaviors that appears in the Science Café context that isn't necessarily bound by topic? Generally, the types of questions and dialogic contributions being put forward by public audiences at Science Cafés are underexplored. Unlike Navid and Einsiedel's, and Dijkstra's studies, which each focus on Science Café events for one topic, this study is analyzing the nature of questions asked at Science Cafés for a range of topics. As such, this study seeks to explore the nature of questions and the patterns of question-asking behaviors that are common to audience participants across Science Café topics, as well as changes in these patterns that might be associated with topic type.

Existing Frameworks for Understanding the Natures and Types of Questions

Previous frameworks for understanding question-asking have focused upon classifying students' questions in classroom settings. Famously, Bloom's Taxonomy (Bloom et al., 1956) designed a hierarchical framework as a teaching tool to classify questioning behaviors according to the complexity of the learning goals, with the recall of facts and basic concepts falling under the tier of lowest complexity, and analyzing, synthesizing and evaluating concepts residing as the layers of highest complexity. Anderson and Krathwohl (2001) rearranged and expanded upon Bloom's work to include an updated form of Bloom's "synthesis" classification, "Creating" or generating and investigating new ideas, as the most complex cognitive behavior of the framework. One limitation of these frameworks for understanding the goals of the question-askers is that they assign value to questions in terms of the cognitive complexity of their asking, rather than pointing toward interpreting the askers' motivations.

(Pizzini and Shepardsen, 1991) also developed a framework for classifying students' questions in terms of cognitive levels, but suggested instead three types of questions: input-level questions, which require students to recall information or to process sensory information; processing-level questions, by which students draw relationships among data; and output-level questions, which encompasses higher-complexity questions as represented by the top tiers of Bloom and Anderson-Krathwohl's taxonomies. With only three categories, this framework is perhaps even more restrictive than Bloom's taxonomy in terms of describing the various shapes questions may take. Taking a similar perspective, Watts, Gould and Alsop (1997) described student questions as falling into one of three categories: consolidation questions, by which students confirm their understanding or explanation for a concept, exploration questions, by which students seek to expand that understanding, and elaboration questions, by which students examine multiple claims or perspectives, test and resolve conflicts, and reconcile their understandings of the concept. In their review of this framework, Chin and Osborne (2006) note that because these categories reflect stages in a student's understanding of the topic, using this framework as a tool requires knowledge of when the question was asked during the process of conceptual development for the data to be meaningful.

Scardamalia and Bereiter (1992)'s research on information-seeking behaviors focused on questions as either knowledge-based (i.e., basic questions to gather information to form foundational knowledge on a topic) or "wonderment" questions, which seek to explain or resolve knowledge discrepancies, and posited that wonderment questions held greater potential to advance knowledge than orienting knowledge-based questions (Pedrosa de Jesus, Teixeira-Dias and Watts, 2003) built a framework from questions generated by undergraduate chemistry students to evaluate the students' willingness to engage in classroom interactions. They proposed a bi-polar construct that would compensate for previous models that value "high quality" questions without allowing for additional data introduced with factors such as question context, intention, and goals. The bi-polar scale that they developed classified student questions along a continuum with "confirmation questions," questions that seek to clarify, differentiate, or define, on one pole, and "transformation questions," questions that seek to restructure understanding, through hypothesis, deduction, argumentation, examination, challenge, or reasoning, on the opposite pole. By reframing question-asking behaviors in a non-hierarchical structure, Pedrosa de Jesus, Teixeira-Dias, and Watts (2003) acknowledged that more complex questions are not necessarily higher value questions since both types of questions can serve to meet the question-asker's needs.

Chin and Kayalvizhi (2002) designed a framework that classified questions as either investigable, such as questions that focus upon comparison, describing relationships, making predictions, problem-solving, or pattern-seeking, and non-investigable questions, which referred to basic information questions where answers could be found handily without deep exploration, complex information questions where solving would involve deep theoretical exploration, or philosophical questions that could not be solved by concrete or evidence-based means.

All of the models previously described were designed to classify student questions in formal classroom settings. One model that was developed to investigate the nature of children's questions relating to informal learning was proposed by Baram-Tsabari and Yarden (2005). Baram-Tsabari and Yarden collected children's science and technology questions submitted to a series of television programs. They categorized the questions according to the topic of interest (i.e., biology, chemistry, physics, nature-of-science, etc.) to assess which streams of science were of greater interest to the students. They also assessed the children's motivations for asking the questions as "applicative," as in questions where the resultant knowledge could be applied to solve a problem, "non-applicative," "factual," or "explanatory," and found that the bulk of questions submitted were non-applicative, with questions trending towards greater application with older question-askers.

While many models exist for describing the natures of questions generated by students and children, especially in formal learning settings, there is a gap in terms of models to describe adult questioning behaviors. This gap is even greater with respect to adult question-asking behaviors within informal learning environments. Some of the models described above may be able to provide some insight to the natures of questions asked by adult audiences at Science Café events; however, they are not designed for informal contexts, nor do they necessarily capture adult or non-student learning goals for asking questions. A question-asking framework based upon data from Science Café data does not exist. A similar approach to developing a novel framework to evaluate learning behaviors in specific informal learning settings has been shown to help us better understand the learning that is happening than the application of formal pedagogical frameworks, as in the case of informal learning through engagement with science center exhibits (Barriault and Pearson, 2010; Barriault and Rennie, 2019). Finally, all of these models work in one direction only, and do not address dialogic modes of question-asking and discussion. None of these existing models seek to identify learning goals for those who participate in information-sharing discussion without asking a question. Knowledge and opinion-sharing are an important element of the Science Café structure, whereby every audience participant has just as much opportunity to exchange their own knowledge as part of the conversation as the expert panelists do, and in doing so are a valuable part of the social constructivist aspect of these events. This study seeks to address this gap in understanding the nature of questions asked in informal learning environments such as Science Cafés as they are designed to encourage discourse and questioning behaviors, and to create a framework that is more appropriate to address informal questioning sessions. Therefore, this study will answer the question: "What is the nature of the questions asked in Science North's Science Café events?"

METHODOLOGIES

Participants

The participants in this study were attendees to Science Café events hosted by Science North in Sudbury, Ontario between November 2010 and April 2019. The participants are specifically those attendees who participated in the panel discussion period of the events and whose participation was captured by the audio recordings of the events. No additional demographics or identifying information was captured for the attendees who specifically participated in the discussion, and the audio recordings do not provide sufficient information to make inferences about demographics.

From November 2010 through April 2019, Science North hosted 55 Science Café events within public venues in the city of Sudbury. In total, audience discussion sessions were transcribed and analyzed for 41 of the 55 Science Café events. Two events from the series were excluded from the study because their format followed the PlayDecide game model, rather than a typical Science Café model, and as such no expert panel was invited to speak and engage with the audiences in an informal question-and-answer period. An additional 12 events were excluded because the recording files were missing and could not be provided for the study.

A total of 510 questions were transcribed from approximately 400 audience participants. The number of audience participants is approximate because, unless the participants clearly identified themselves as asking additional or follow-up questions, each question was counted as asked by a new audience participant. The number of questions within each Science Café event recording ranged from 1 to 34 questions per recording, with a median of 12 audience questions asked. Three Science Cafés included in this study had fewer than five questions available for analysis. In all cases, these low values were due to audio recording failures.

Seven questions were excluded from the transcription and so were excluded from analysis because the quality of the recording was too poor to transcribe, six because the participant was not using the microphone to speak, one because the recording cut off the question.

The Science Café recordings are being used with permission from Science North. The event recordings were collected from 2010 to 2019 by Science North, and all event recordings were released to the public on the Science North website or in podcast form. The audience were made aware that their voices would be recorded at the event and were given the option to submit their questions either electronically on Twitter or directly to the event moderator on slips of paper if they did not consent to having their voices recorded. As such, no further permission was requested for using these audio recordings for research purposes.

Designing the Framework

In order to develop a framework for understanding the nature of the questions being asked by Science Café event participants, the primary strategy for qualitative data analysis (QDA) of these data was a grounded theory approach. This approach required multiple passes of the Science Café transcripts to iterate upon the framework and reapply it to the data until theoretical saturation was met.

First pass: all transcripts were read and notes were taken for potential question-type categories. Early proposed question types based on impressions from transcripts included *Factual Questions* (titled Clarification Questions), *Affective Questions* (*Bias and Opinion-Seeking Questions*), *Hypothetical Questions (What if Questions)*, and *Asking for Advice*. It was also noted that there existed participant engagements within the transcripts that did not pose questions and that these engagements should receive non-question codes.

Based on this pass, two parent codes were created with respect to question-asking behaviors: Information-Seeking Questions and Non-Information–Seeking Questions. The question-type categories identified during the first pass (described above) were included in the framework as subcategories of Information-Seeking Questions.

Second pass: The framework developed during the first pass was applied to all transcripts. All question-asking behaviors were coded as either Information-Seeking or Non-Information–Seeking Behaviors, and Information-Seeking Behaviors were categorized as either *Factual Questions, Affective Questions, Hypothetical Questions,* or *Rhetorical Questions*.

During this analysis, four new Information-Seeking question types were identified: *Relevance Questions* (the previous *Asking for Advice* question type would be housed here), *Rhetorical Questions, and Follow-Up Questions*. These question-type categories were created to code questions that did not fit into the existing first pass framework.

Four categories for Non-Information–Seeking question types were also identified: *Sharing Knowledge or Expertise Without Follow-Up Question, Storytelling or Anecdote Sharing, Criticism of Panelists' statements,* and *Sharing Personal Opinion on Topic* to add a second layer of description for types of Non-Information–Seeking Questions found during analysis.

In order to clarify the criteria for different Information-Seeking question types and to differentiate between these question types while coding, question subtypes were identified based on observations taken during the coding process.

Affective Question subtypes:

- Questions about panelists' personal opinions or practices;
- Understanding panelists' personal goals and desired outcomes; and
- Questions about beliefs versus facts

Factual Question subtypes:

- Wh-questions (e.g., *Who, What, Where, When, Why*);
- Asking for definitions, fact-seeking questions, explaining a concept; and
- Causal questions (e.g., *How. . .?*)

Hypothetical Question subtypes:

- Hypothetical (e.g., *What if..?*) questions; and
- Future-looking questions/predictions

Relevance Question subtypes:

- Relating topic to self (e.g., *Is this about personal goals or objectives that I share?*);
- Asking panelists to relate topic to asker (e.g., *Why does this matter to me? How does this relate to my personal goals?*); and
- Asking for advice

Rhetorical Question subtypes:

- Hostile question content/challenges to panelists (e.g., *Who cares? What difference does it make?*); and
- Seeking Confirmation (e.g., *Isn't this..?, Don't you think..?, ...right?*)

Follow-Up Question subtypes:

- Agreement;
- Persistence (disagreement or repetition of original question);
- Providing own explanation; and
- New, unrelated question

Third pass: When this new framework was applied to the transcripts and data was re-coded, the question subtypes were refined to their final state with a few exceptions:

- A new Information-Seeking question type, *Solution-Oriented Questions* was added to encompass a pattern of askers' questions that either suggested solutions for the panelists to evaluate or requested potential solution ideas from the panel.
- The *Follow-Up Question* question type was removed from Information-Seeking Questions parent code to exist as an additional coding category that may be double-coded with either Information-Seeking Questions or Non-Information–Seeking Questions, where applicable. This choice was made because discrete follow-up questions may display either Information-Seeking or Non-Information–Seeking Questions and, while relevant behavioral information in terms of describing how a question-asker is engaging with others at a Science Café event (e.g., engaging in dialogic behaviors), the question category did not point to information about the asker's learning goals or to the nature of the question being asked.
- A new question subtype, *Humorous Questions*, was added to the Rhetorical Questions question type, to address instances where askers used humor to ask questions that otherwise did not fit with other coding categories.
- A new question subtype, *Philosophical Questions*, was added to the Affective Questions type, to capture questions of a philosophical nature (and as such based heavily within personal values and beliefs) that did not otherwise fit into an existing question subtype.
- Types of Non-Information–Seeking Questions were refined to *Opinion or Knowledge Sharing* (combining opinion-, knowledge/expertise-sharing elements into one category), *Experience Sharing* (which captures lived experiences and personal anecdotes), *Criticism of panelists' statements, Answering Audience Questions.* As well, a new type of Non-Information–Seeking Question, *Promotion of event or personal cause* was added to code instances where askers used their time at the microphone to promote an event or cause to the audience in the room rather than to engage the panel or audience with a question or discussion on the Science Café topic.
- Previously, only audience questions directed to the panel were being included in the study. At this juncture, the decision was made to include audience questions directed toward non-panelists or other audience members. This decision was based on the format of the Science Café, which, by its nature, encourages discussion or conversation, rather than a didactic or transmission model of information sharing. In this respect, there is value to questions posed to non-panelists within the room, just as previous passes of the data coded for the behavior of audience members *answering* other askers' questions. This code type exists outside of the Information-Seeking/Non-Information–Seeking parent code dichotomy, as in the case of the *Follow-Up* questions code, as this attribute can exist within both parent code categories. The attribute of who the asker is addressing with their question does not change the learning goal of their question.

Fourth pass: During previous passes, the question subtypes had been used as coding guidelines, or criteria, for coding questions to Information-Seeking and Non-Information–Seeking question categories. In this pass, all subtypes in the framework were included in the transcript re-coding process. Therefore, every coded question would be assigned three layers of the framework (or two, in the case of Non-Information–Seeking Questions).

Theoretical saturation was reached upon reviewing and re-coding all questions to a question subtype at this stage. The only major change to the framework, other than refining type and subtype titles, was to dissolve the Personal Relevance Question subtype *Asking panelists to relate the Science Café topic to the asker personally*, as there was only one question coded to this category and that question met the criteria to be recoded to the Personal Relevance Question subtype *Relating Science Café topic to self*. The distinction between the two categories was not strong enough to maintain them separately. Overall, Author 1 generated the framework and coded the transcripts for all Science Café questions; Author 2 verified the fit of the framework by applying it to a sample of 65 randomly selected questions from the transcripts.

Guiding Principles

In building the framework, every effort was made to avoid value judgments on the learning goals of the behavior categories and their subtypes. The goal of this taxonomy is not to qualify some behaviors as superior or inherently more desirable; rather, it is intended as a tool to understand the motivations or learning goals of event participants who engage in panel discussions at Science Café events and the natures of the information that they do (or do not) seek.

Classifications within the framework are not mutually exclusive; especially if participants are being coded from an audio or audiovisual source (rather than strictly text-based), participant questions can be coded to more than one category within a question-asking behavior.

All language, but especially spoken language, is rich in meaning, including intention, tone, and semantic meaning. Early research in question-asking behaviors has largely focused on text-based questions, which does not encompass the additional information that can be gathered by studying

TABLE 1 | Comparison of question types at Science Café events featuring Challenging Topics (n = 24).

Question type	Number of questions asked (challenging science cafés)	Percent of questions asked (challenging science cafés)	Mean	Number of questions asked (all science cafés)	Percent of questions asked (all science cafés)	Mean	*p*-value
IS - Affective Questions	84	26.33	3.500	120	19.93	2.927	0.183
IS - Factual Questions	115	36.05	4.792	256	42.52	6.244	0.020*
IS - Hypothetical Questions	58	18.18	2.417	87	14.45	2.122	0.495
IS - Personal Relevance Questions	12	3.76	0.500	27	4.48	0.046	0.005*
IS - Rhetorical Questions	27	8.46	1.125	39	6.48	0.951	0.556
IS - Solution Oriented Questions	35	10.97	1.458	74	12.29	0.180	0.199
NIS - Answering Audience Question	3	0.94	0.125	14	2.33	0.341	0.027*
NIS - Criticism	3	0.94	0.125	3	0.50	0.073	0.577
NIS - Experience Sharing	7	2.19	0.292	20	3.32	0.488	0.094
NIS - Opinion or Knowledge Sharing	62	19.44	2.58	121	20.10	2.951	0.560
NIS - Promotion	2	0.63	0.083	5	0.83	0.122	0.509

questions as they are posed in naturalistic settings; however, Carlsen (1991)'s work approaches questions from a sociolinguistic perspective and suggests that we approach three features of questions: context, which includes the speakers (in the case of this study, the audience participant, the panelists, and their relationships to each other), and where the question fits into the larger discourse between all parties; content, which refers to what is being talked about and associated knowledge; and the responses and reactions of all parties engaged in the discourse adjacent to the question-asking. As well, question askers are not necessarily conscious of their learning goals when they formulate a question and may in fact have more than one goal in mind. Taking these aspects of language and learning into account lends the data in this study to double-coding under more than one Question Type within the framework (such that data often adds up to more than 100% when taken together). As well, to reflect the nuances of language, the Question Types in this framework are not mutually exclusive types: a question may have elements of an Affective subtype while also being a Hypothetical question; a Personal Relevance-type question may also seek Factual subtype information. There are limitations within this model, however; Information-Seeking Questions and Non-Information–Seeking Questions are mutually exclusive. For example, if an asker engages by sharing a personal anecdote and then follows that anecdote with a question or a request for comment, then that anecdote is coded as part of the Information-Seeking Question, since it is a preamble to the question, providing context to the person(s) to whom the question is directed. Only if that anecdote were *not* followed by a question would it be coded as a Non-Information–Seeking Question.

Applying the Framework

To evaluate the framework as a tool for understanding the natures of audience participants' questions, the framework was applied to three samples of the Science Café data (samples were groupings of Science Cafés by topic type) and the resultant question-type data for those samples were compared to the data for all Science Cafés. The three sample groupings were Challenging Topics (e.g., topics that may be unfamiliar or less accessible to the public, such as gene editing or particle physics), Health Topics (i.e., events focused on human health conditions, such as hepatitis, diabetes, or fatigue), and Local Interest topics (e.g., topics of specific interest to local attendees; in the case of Sudburians, such topics include mining and environmental restoration). The differences between question-asking behavior data from the sample groupings in comparison to the data from all Science Cafés was evaluated using two-tailed one-sample t-tests. The null hypothesis states that there is no difference between the sample grouping means for each type of question-asking behavior when compared to the overall Science Café means ($p > 0.05$). Results for which the null hypothesis is rejected ($p < 0.05$) are indicated by an asterisk (*) in **Tables 1**, **2**.

RESULTS

Explanation of the Framework

Using a grounded theory approach to the data analysis, the framework was developed to classify participant engagements according to their learning goals (*See* **Figure 1** for the full framework). This process yielded two main categories of question-asking behaviors: *Information-Seeking Questions*, by which Science Café attendees participate in the discussion period of the event with the goal of receiving information; and *Non-Information–Seeking Questions*, by which Science Café attendees participate in the discussion period of the event with goals that do not involve receiving information from the panelists or other Science Café participants.

Each one of the categories in the taxonomy contains, in order: *1*) a definition of the question category and its overarching learning goal, including considerations for classification; *2*) a description of the learning objectives(s) for each of the category's

TABLE 2 | Comparison of question types at Science Café events featuring Health Topics (n = 11).

Question type	Number of questions asked (health science cafés)	Percent of questions asked (health science cafés)	Mean	Number of questions asked (all science cafés)	Percent of questions asked (all science cafés)	Mean	*p*-value
IS - Affective Questions	26	13.68	2.364	120	19.93	2.927	0.325
IS - Factual Questions	105	55.26	9.545	256	42.52	6.244	0.091
IS - Hypothetical Questions	18	9.00	1.636	87	14.45	2.122	0.419
IS - Personal Relevance Questions	10	5.26	0.909	27	4.49	0.046	0.013*
IS - Rhetorical Questions	6	3.16	0.545	39	6.48	0.951	0.132
IS - Solution Oriented Questions	20	10.53	1.818	74	12.29	0.180	0.965
NIS - Answering Audience Question	7	3.68	0.636	14	2.33	0.341	0.315
NIS - Criticism	0	0	0	3	0.50	0.073	--
NIS - Experience Sharing	6	3.16	0.545	20	3.32	0.488	0.878
NIS - Opinion or Knowledge Sharing	36	19	3.273	121	20.10	2.951	0.738
NIS - Promotion	2	1.05	0.182	5	0.83	0.122	0.634

question subtypes; and *3*) illustrative examples of questions that fit each question subtype.

Information-seeking Questions

Information-seeking questions are tools that allow Science Café participants to request information or solicit responses from the person(s) receiving the question. The following sub-categories separate information-seeking questions by the learning goals of the asker, or the type of information being sought (**Table 3**).

Non-information–Seeking Questions

Audience participants engage in Non-information–Seeking Questions when their role in the dialogue is not as a question-asker or information-seeker, but rather as information contributors. The information that audience participants contribute to discourse may be factual or affective, and it may be directed toward the panelists or towards other audience members. The most important criterion for characterizing Non-Information–Seeking Questions is the lack of an actual question, whether embedded within statement or following it up. The presence of a question automatically transforms Non-Information–Seeking elements into part of (or perhaps context for) an overall information-seeking behavior. The types of Non-Information–Seeking Questions coded are described below (**Table 4**).

Additional Question Codes

These codes can be used to further characterize behaviors across multiple types and/or subtypes. While they do not indicate the nature of questions in terms of learning goals, they serve to reveal relevant additional information about audience participant behaviors in the context of their engagement during Science Café discussions.

QUESTIONS DIRECTED TOWARD NON-PANELISTS

This information-seeking question type is not included in the main taxonomy because the asker is not addressing the event panel; however, the behavior is interesting in that it is used to either leverage information from the audience to support the asker's statement, or it demonstrates dialogic engagement between audience members. If rich intra-audience discussion is a goal for a science café event, the presence of questions

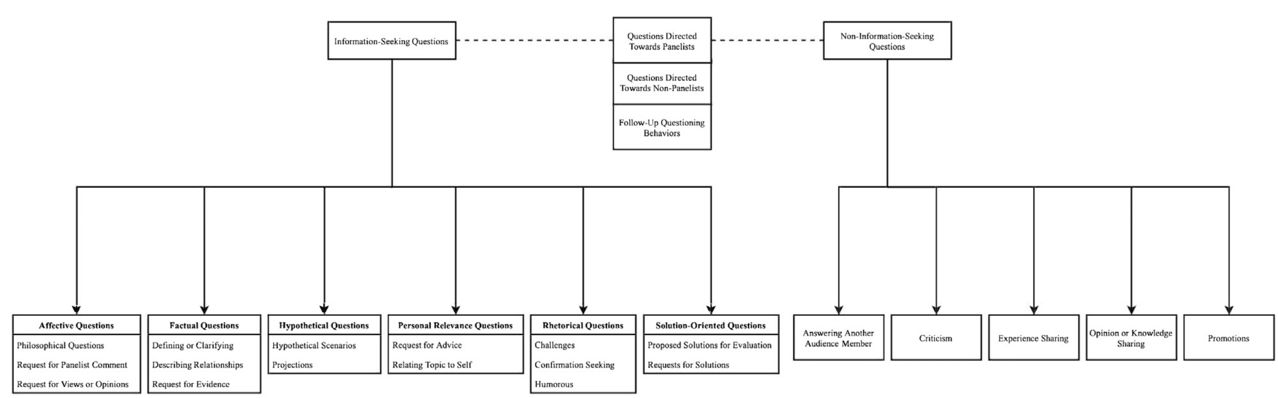

FIGURE 1 | The Nesseth taxonomy of questions based on learning goals.

TABLE 3 | Framework layers of Information–seeking question types, subtypes, and examples.

Question type	Question subtype	Examples
Affective Questions Learning Goal: Affective questions are asked to learn the panelists' personal views, opinions, or interpretations regarding information, rather than strictly factual responses. These questions will tend to be framed in a way that centers the request on the person(s) receiving the question, e.g., "Do you think?", "How do you feel..?"	**(i) Request for panelists' views or opinions** The goal of the asker's question is to understand the question topic through the lens of the panelists' personal views, opinions, or interpretations of information, rather than simply receiving factual information about the topic	"How do you feel — so you all expressed your views about how the environment and genetics are so complicated. How do you feel about genetically modified organisms? Genetic engineering in general?" "[...] do you really feel the mining companies in Sudbury, in the basin, are really prepared for embracing technology?"
	(ii) Broad philosophical questions Philosophical questions are asked to request that the panelist(s) provide their reflections on broader, fundamental ideas based on the panelists' personal views, values, and beliefs. These questions typically are theoretical in nature and, as such, cannot be answered with factual information, only conjecture	"Without consciousness, do we own our body?" "We've talked a lot about the impact of both genetics and the environment and how they work together. Um, my question is: where does free will play into this?"
	(iii) Requests for comment Requests for comment are framed as a way of seeking affirmation from the panelist(s) *via* panelists' opinions agreeing with theirs. Structurally, they typically follow the asker sharing their opinion or thoughts with the panel	"And, I don't know: do you want to comment on that comment?" "And so I was wondering what you guys think about that strategy."
Factual Questions Learning Goal: Factual questions seek to uncover fact- and/or evidence-based information, including definitions, explanations, and clarifications of concepts, elucidations of relationships (e.g., causal relationships), and descriptions of real events or panelist experiences	**(i) Definition or Clarification** The aim of definition or clarification questions is to receive explanations of concepts or clarifications of ideas. So-called "Wh- questions" (questions beginning with Who, What, Where, When, or Why) are encompassed within this subtype. This subtype also includes closed fact-seeking questions that can be answered with a yes or no	"Is there research that you can speak to that kind of clears that up a little bit?" "Who makes these detectors?"
	(ii) Description of Relationships This subtype seeks factual information regarding relationships, such as causal relationships, correlations, or comparisons and contrast relationships	"[...] how does behavior, like say, suckling on breasts in mice or inhaling particulate matter lead to fairly specific organic chemistry changes within the nucleus of the cell?" "How does it compare to other countries?"
	(iii) Requests for Panelists' Lived Experience Rather than seeking views or opinions, this subtype seeks to learn panelists' concrete, lived experience as evidence to support an idea or argument	"And do you find this same problem in your scientific papers that I'm seeing in engineering papers?" "So the question is: what types of medical emergencies have you encountered that marijuana might have been involved in?"
Hypothetical Questions Learning Goal: The goal of asking hypothetical questions is to gain panelists' views, based on extrapolating from current facts or personal speculation, regarding the future or regarding hypothetical scenarios	**(i) Hypothetical Scenarios** Hypothetical scenarios ask the panelists to speculate on given hypothetical scenarios and usually involve the panelists' personal views, opinions, beliefs, and/or personal interpretations of the asker's hypothetical scenario	"[...]can we imagine two different islands and on one island we have 100 women and one man, and on another island we have 100 men, one woman. And from female-male behavior-point of view or biological evolution point of view, if somebody were to visit these two isolated islands after 2 yr, what kind of a change you will *(sic)* expect?" "As well, a proper question: next week and at the opening: fantastic! You flip a switch and you discover dark matter. What next?"
	(ii) Projections Requests for projections seek specifically for the panelists to evaluate current data and formulate projections or predictions based on this data	"Can you give a prediction of what timeframe that might be? I know it's a bit of a crystal ball thing, but where it is right now and where it's looking to go?" "So, in the next 20 yr, what, what do you project happening? Is it more successful research? Is it more research is being involved that can perhaps advance that, that, that you want to be advanced?"

(Continued on following page)

TABLE 3 | (*Continued*) Framework layers of Information–seeking question types, subtypes, and examples.

Question type	Question subtype	Examples
Personal Relevance Questions Learning Goal: The goal of the personal relevance question is to relate the topic personally to the asker. The asker seeks to make a personal, often emotional, connection to the topic to either support understanding of the topic or to deepen their appreciation for that topic's importance or relevance	**(i) Asking for Advice** As a goal, the asker is seeking advice from the panel, either to assist themselves, or to assist others, in making a decision or taking an action	"Who do you go to see if, like we had a young girl, she couldn't even drive her car home, we had to drive her car home. She got so stressed out and sick. And I think, who do you recommend these people to go to see?" "So, what do you guys recommend for people trying to eat more of a plant-based diet and where they can get their so-called protein and make sure they're eating a well-rounded diet?"
	(ii) Relating Topic to Self By relating the discussion topic to themselves and making personal connections, the asker seeks deeper understanding or reason for deeper interest in the topic	"And what I am, just with my two neighbours, so...the question always comes back: why should I care?" "Like, why is it that my friends in New York and some friends in Toronto are on PREP but then, like, what's wrong with Canada with that respect?"
Rhetorical Questions Learning Goal: Rhetorical questions are vehicles for assertion. They allow the asker to emphasize a point or to reinforce an idea or statement, to seek confirmation of personal view, to challenge panelists or establish disagreement	**(i) Challenges** Challenges allow the asker to establish disagreement, with the goal of provoking the panelists to either revisit or deepen their argument. This subtype may also encompass "playing the devil's advocate."	"You talk about these scientists having this discussion. I wonder if scientists can also be blinded by the fact that they never actually tested that clouded their decision to allow it to go that long." "So, who is going to argue on the positive side? Even that might not be true."
	(ii) Confirmation-Seeking Questions Confirmation-seeking questions, often appearing as filler language or a non-question (e.g., "right?") seek to assert a statement while asking for the panel to confirm or agree with the statement	"If most of us feel that way, aren't we then really talking about consciousness?" "It sounds as though the structure at the MNR changes quite frequently, right?"
	(iii) Humorous Questions Humorous questions can serve a few roles. They may be used as a way for the asker to build comfort prior to entering discourse with a "real" question, or to couch a true information-seeking behavior within a joke to avoid negative affect, such as embarrassment about their own lack of knowledge; they may be used to seek social validation from the panel or other audience members; or they may be used to elicit a positive affective response from the panel	"[...] can I be the first volunteer to be your guinea pig in the environmental chamber, please?" "So I have two questions: one is quite easy, uh, the second one's a bit longer. The first: dark matter? Is that similar to Star Trek's equivalent to anti-matter?"
Solution-Oriented Questions Learning Goal: The goal of solution-oriented questions is to prompt discussion towards a solution to an issue raised either directly or indirectly by a Science Café topic	**(i) Proposing solutions for evaluation** This subtype involves the asker proposing an idea for a solution and soliciting the panel's opinion as to that proposed solution's feasibility, based on their expertise	"Just on the green energy thing. Um, I wondered how much, how long the lifespan of the Superstack would be and if it would be feasible to clad it in solar panels rather than tear it down for energy?" "Just a wild idea: have people considered the use of virtual reality on animals to prepare them for life in the wild?"
	(ii) Requests for solutions This subtype occurs when an asker identifies an issue and sees a need for a solution, but does not have a solution to propose to the panel; rather, they deliver the need for a solution to the panel and ask for the panel to consider and describe possible solutions	"What do we do?" "How do we build a culture that would be excited about exploring science?"

directed toward non-panelists may be used as a relevant and measurable engagement behavior.

Examples:

- [in response to another audience member] "Why?"
- "[...] how many people in the audience were born 1981 or onwards?"

Follow-Up Questions

Follow-up questions were also coded as part of audience engagement analysis because they indicate depth of engagement, either in terms of an asker's interest in asking multiple questions of the panel, or in terms of an asker engaging in a dialogic, conversational pattern of engagement with the panel. Follow-up questions may be either discrete, pre-planned questions asked in succession, the same

TABLE 4 | Framework layers of non-information–seeking question types and examples.

Question type	Examples
Answering Other Audience Members This behavior occurs when an audience member has knowledge or an opinion related to another asker's question and chooses to share this information, either to fill a perceived gap in the panel's response to asker, or to add to the panel's response	"Um, I'd like to address the specific question that was asked just previous to this, with regards to whether the money would be better spent on some sort of medium, um, like radio... I still feel that any type of medium wherever you actually want to advertise, wherever you can get the best bang for your buck, would be ideal." "If I can just add a bit to that. Having both diseases makes each other worse in the long term. Hep C will complicate HIV, and HIV will complicate the Hep C in terms of treatment."
Criticism Criticism allows for the asker to share their displeasure, disagreement, or other negative affect with the panel and greater audience. This behavior can be differentiated by the "challenges" subtype of the Rhetorical Question categorization in that the asker seeks to make their assertion of disagreement without the expectation of response from the panel	"Um, I'm going to play "devil's advocate" and say that, and at risk of shocking the entire audience, I think that you are, all of you, micturating into a very strong breeze." "I just wanted to ask, tell you I mean, what I don't like about the game — their situation is different, but with the children? I just find that all the people that are in the games all look perfect again. You know what I mean? So, that really bugs me. I like that show with Johnny Depp where he was Captain of the Caribbean? Everybody was like a monster. Like they were all different monsters. I just find that it's just too bad that that game has to have everybody looking perfectly shaped and very beautiful and it's sad that part of me in the game."
Experience Sharing Experience Sharing provides the asker with a vehicle for describing their lived experience to the panel and greater audience as evidence to support their argument with respect to the Science Café topic. This behavior does not precede a question or other information-seeking engagement	"Well, a supplementary, and I don't want to get too, sort of, detailed about it, but I'd, I'm a physician. I do talks on the physical and the, you know, health risks to do with climate change." "I come from a rural community, a First Nation community on Manitoulin Island and I'm, it's good to hear the challenges that people face in the city, that we also face in a rural community."
Opinion or Knowledge Sharing Opinion or Knowledge Sharing provides the asker with a vehicle for asserting their personal views, beliefs or values, or to share their personal knowledge relating to Science Café topic. This behavior does not precede a question or other information-seeking engagement	"Oh I was just going to add that his bone marrow donor? He was one of those few people who is non-susceptible to HIV. That mutation that's present in Europe." "And, uh, I think that we could learn a, for example, um, I think it all has to do with our biochemistry and, um, take a type I diabetic and feed him all you want, he's not gaining weight. And, uh, I think we need to look at, uh, these things from a very personal way, because everybody's biochemistry is different."
Promotion When presenting promotion statements, participants are taking advantage of the gathering at the event to use the discussion period as a platform to bring awareness to a person, organization, event, or cause, and/or are inviting other event participants to engage in a call to action	"So, if anyone has stories they would like to share, or anecdotal evidence that they have been able to protect their information thanks to this new law, we can show them that it's working. Feel free to connect with the coalition. We'll be happy to share your stories for you. Thank you very much for the presentation." "So, I suggest to all of you to check it out and get involved with citizens' climate lobby. So, that was the non-political pre-debate announcement."

panelist returning to the microphone ask an additional question, or the asker engaging in a back-and-forth discussion with the panelists, responding to the panel's response to their questions with questions addressing the new information provided by the panel.

- "I've got another question, it's that, with regards to, um, is there anything that could, perhaps, buffer the effects of this?"
- [in response to a panelist's response to their question] "So, our policy decisions on conservation are driven by aesthetics?"

Information-Seeking Questions Among Science Café Participants

The majority of audience participant engagements at Science Café events involved information-seeking questions (76.41%) as opposed to non-information–questions (23.59%). In terms of information-seeking questions, askers most often sought factual information (42.52%); in particular, askers sought definitions of terms or clarifications of concepts from the panel. The second most popular form of information-seeking question came in the form of affective questions (19.93%), in particular, questions that specifically sought the panel's views or opinions (14.95%) (**Figure 2** and **Table 5**).

Non-Information–Seeking Questions Among Science Café Participants

During question and answer sessions at Science Café events, just over one-fifth (23.59%) of audience participant engagements were Non-Information–Seeking questions. Most of these questions (20.10% of all engagements) involved the participant sharing their personal opinion or knowledge without including a question in their remark. Participants at Science Café events were much less likely to approach the microphone for the purposes of sharing personal experience (3.32%), answering other audience members' questions or engaging in dialogue at the microphone with another audience member (2.33%), using the event as a platform to promote events or personal causes (0.83%), or criticizing the panelists (0.50%) (**Figure 3** and **Table 5**).

Other Engagement Behaviors Among Science Café Participants

Types of dialogic behaviors that went beyond the two-step practice of *1*) posing a question to the panel, and *2*) receiving the answer from the panel included: *1*) follow-up questioning, by which audience participants either responded to the panelists' response with a related question, repeated their own question, or

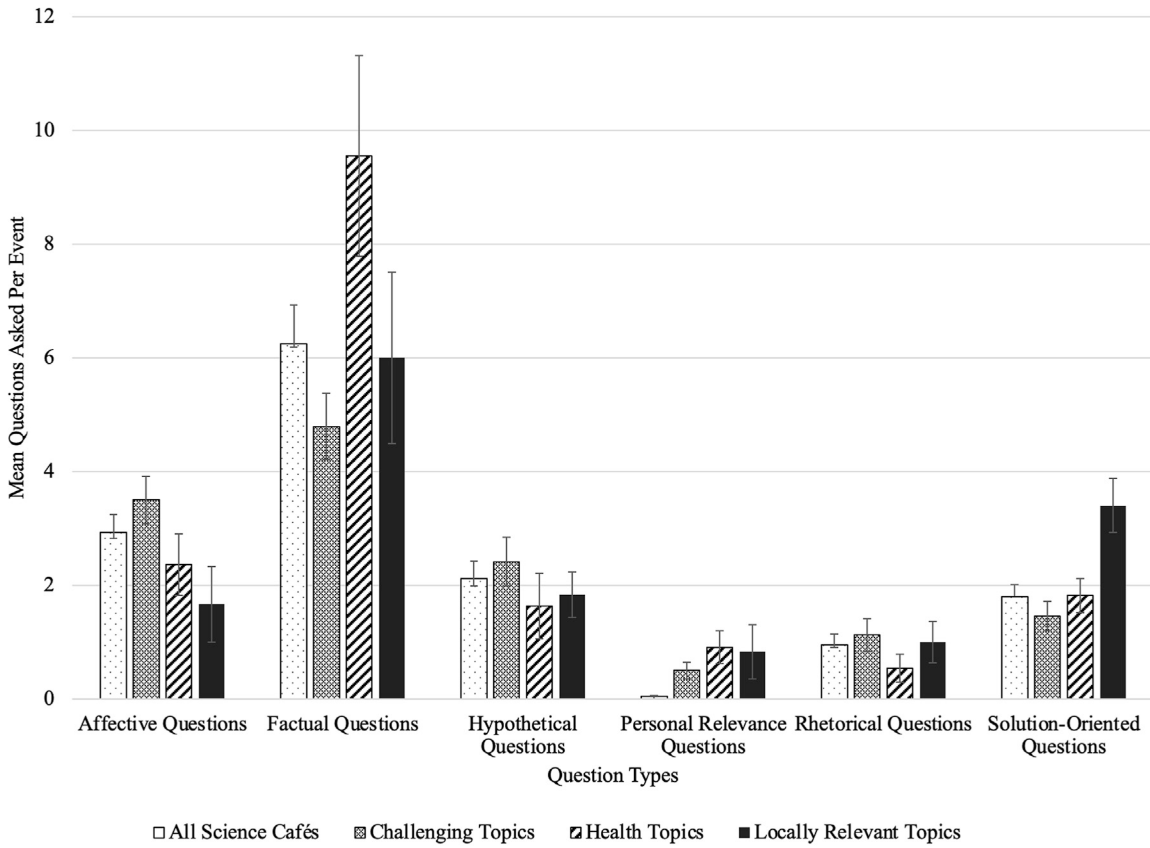

FIGURE 2 | Information-seeking question types for all Science Café events.

continued a line of questioning with a new, unrelated question, and *2*) questions posed to other audience members to invite their input in the discussion. Follow-up questions made up approximately 13% of the engagements during Science Café discussions. Engaging other audience members was a less common behavior, with fewer than 1% of engagements being addressed to non-panelists. There was no significant difference in these dialogic behaviors across different Science Café topic types.

Impact of Science Café Topic on Asker Behavior

The primary application of the framework is to measure the frequencies of question types and subtypes asked by Science Café participants in order to gain insights about the natures of questions being asked at these events. To evaluate the framework as a tool capable of providing comparative data about the natures of questions being asked by audience participants when specific topic types are featured, the framework was applied to groups of Science Cafés (grouped by topic type), and the question-type data from these groupings was compared to the total data for all Science Café events. When grouped by topic, three major categories of Science Cafés emerged: *1*) Challenging topics (n = 24), which consist of complex, challenging, and/or theoretical topics that likely do not have immediate personal relevance to the audience, or topics to which the audience may have had limited exposure, such as particle physics or genetic engineering; *2*) Health Topics (n = 11), which comprise topics that are immediately relevant to human health, such as diabetes and depression, and fatigue; and *3*) Locally-Relevant Topics (n = 6), which consist of topics that are specifically relevant to the local interests of, or local issues affecting Science Café attendees (in this case, as predominantly residents of the City of Greater Sudbury), such as mining or local environmental remediation efforts (known colloquially in this area as "regreening").

As we can see in **Table 1** above, when the Science Café features a Challenging topic (e.g., biotechnology or gene editing), we actually see a decrease in Factual question types and an increase in Personal Relevance question types. The percentage breakdowns for subtypes of Affective Questions were comparable to the overall breakdowns for those subtypes across all Science Café events. questions is that the learning goal of the asker isn't to seek definition or clarification of these topics or the issues surrounding them in evidence-based terms (terms which would have been presented to some degree during the panelists' presentations in the first half of the Science Café event); rather, they are seeking to build their knowledge and opinions on these topics or issues using by asking the expert panelists to draw connections to the topic on terms that are personally relevant to the question asker. This is an interesting

TABLE 5 | Frequencies of all types and subtypes of question-asking behaviors.

Type of question	Frequency	% of total questions
Information Seeking	460	76.41
Affective Questions	120	19.93
Philosophical Question	21	3.48
Request for Panelist Comment	12	1.99
Request for Views or Opinions	90	14.95
Factual Questions	256	42.52
Define or Clarify	197	32.72
Describe Relationships	55	9.14
Request Evidence of Lived Experience	17	2.82
Hypothetical Questions	87	14.45
Hypothetical Scenarios	61	10.13
Projections	26	4.32
Personal Relevance Questions	27	4.49
Request for Advice	11	1.83
Relate Topic to Self	17	2.82
Rhetorical Questions	39	6.48
Challenges	7	1.16
Confirmation-Seeking	28	4.65
Humorous	5	0.83
Solution-Oriented Questions	74	12.29
Proposing solutions for evaluation	28	4.65
Requests for solutions	50	8.30
Non-Information–Seeking	142	23.59
Answering Another Audience Member	14	2.32
Criticism	3	0.49
Experience-Sharing	19	3.16
Opinion or Knowledge Sharing	121	20.10
Promotion	5	0.83
Additional Engagement Codes	--	--
Questions Directed Toward Non-Panelists	5	0.83
Follow-Up Engagements	88	14.62

finding that contrasts with previous research conducted by Scardamalia and Bereiter (1992), which found that students generated mainly Factual-type "basic information" questions for topics that were less familiar to them, but concentrated on "wonderment" questions (defined by Scardamalia and Bereiter (1992) as questions that reflect curiosity, puzzlement, or speculation) when they were more familiar or comfortable with the subject matter being discussed.

When the Science Café topic is focused upon human health, the results show a shift in asker behavior that also favors Personal Relevance question types (**Table 2**). indicating that the goals of participants at Science Cafés featuring health topics is to discuss health issues in terms that are applicable to their personal experiences. We might infer that these question askers are interested in concrete information over abstract because health issues are inherently more personal, more likely to affect them or someone that they know, than impersonal-seeming topics such as foreign aid projects or particle physics. Question-askers are seeking information that they might be able to apply in the case that they or someone close to them is affected by the health issues being discussed.

All of the Science Café events included in this study were held at locations in Sudbury, Ontario, Canada, and the majority of attendees are assumed to have been either permanent or temporary (i.e. student) inhabitants of the Greater Sudbury region. While any topic addressed during a Science Café might be filtered through a local lens, six Café topics in particular addressed issues that are highly relevant to the people of Greater Sudbury, their culture, and the City's economy (e.g., regreening or environmental restoration, mining). Topics known to be of high interest to local audiences yielded different question-asking patterns, most notably a large shift toward Solution-Oriented question types (**Table 6**). This shift in Information-Seeking Questions indicates a tendency towards ownership or personal affiliation with the topic and a desire to make improvements, whether by suggesting solutions to the panel for issues that they have perceived relating to the Science Café event topic, or by identifying the need for a solution and entreating the expert panel to conceptualize potential solutions. Interestingly, while audience participants did engage in sharing personal experiences and opinions as Non-Information–Seeking Questions, there is no significant increase in these behaviors when compared to all Science Café events. This is likely because these sharing behaviors were often tied to a Solution-Oriented (or other) learning goal and so were not captured separately as Non-Information–Seeking Questions.

Overall, the types of questions asked in these three groupings of Science Café types did not yield significant shifts in non-information–seeking question asking behaviors when compared to the full set of questions asked by audience participants at all Science Café events included in this study (**Figures 2**, **3** and **Tables 1**, **2**, **6**). One exception was measured: audience members who participated in Science Cafés featuring a Challenging topic of

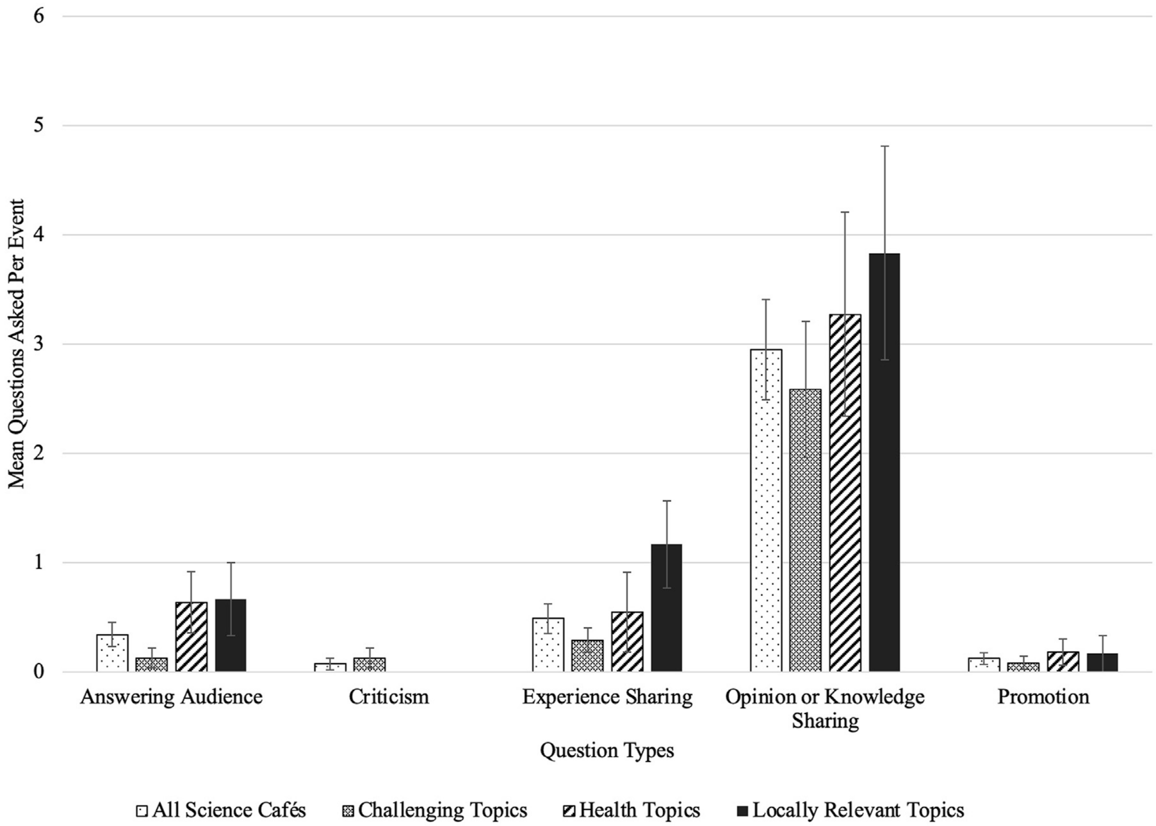

FIGURE 3 | Non-Information-seeking question types for all Science Café events.

TABLE 6 | Comparison of question types at Science Café events featuring Locally-Relevant Topics (*n* = 6).

Question type	Number of questions asked (locally relevant science cafés)	Percent of questions asked (locally relevant science cafés)	Mean	Number of questions asked (all science cafés)	Percent of questions asked (all science cafés)	Mean	*p*-value
IS - Affective Questions	10	9.09	1.667	120	19.93	2.927	0.117
IS - Factual Questions	36	32.73	6.000	256	42.52	6.244	0.877
IS - Hypothetical Questions	11	10.00	1.833	87	14.45	2.122	0.504
IS - Personal Relevance Questions	5	5.61	0.833	27	4.48	0.046	0.160
IS - Rhetorical Questions	6	5.45	1.000	39	6.48	0.951	0.898
IS - Solution Oriented Questions	19	17.27	3.400	74	12.29	0.180	0.020*
NIS - Answering Audience Question	4	3.64	0.667	14	2.33	0.341	0.374
NIS - Criticism	0	0	0	3	0.50	0.073	--
NIS - Experience Sharing	7	6.36	1.167	20	3.32	0.488	0.152
NIS - Opinion or Knowledge Sharing	23	20.91	3.833	121	20.10	2.951	0.409
NIS - Promotion	1	0.91	0.167	5	0.83	0.122	0.799

discussion were less likely to engage in answering other audience members' questions (**Figure 3** and **Table 1**).

DISCUSSION

The results of analyzing the transcripts of 41 Science Café discussion sessions allowed for the development and application of a coding framework of questions based on the asker's learning goals. In turn, the application of this framework allowed us to understand the nature of the questions being asked by audience participants at Science Café events.

The framework took the form of a taxonomy of question types (**Figure 1**), wherein emergent themes in how audience participants engaged during Science Café discussion sessions revealed an order of behaviors. Constructing the framework as a taxonomy reflects this order in the nature of questions and behaviors from broad descriptors (e.g., whether the behavior was information-seeking or not), and moving toward more specific descriptions of the nature of those behaviors (e.g., whether that information-seeking behavior was more specifically asking questions that seek factual information, and then whether that factual information sought was to describe relationships).

The classification schema for this taxonomy represents audience participant behaviors in terms of the intent behind their participation during Science Café discussion sessions. These intents can be described as learning objectives, and because these sessions are dialogue events, learning objectives encompass information that the audience participants wish to receive (Information-Seeking Questions) as well as information that the audience participants wish to impart (Non-Information–Seeking Questions). As revealed by the analysis of the audience participants' questions, the learning objectives are not limited to the acquisition of factual information (nor the delivery of strictly factual information); rather, when engaging with a live panel of experts, audience participants are also interested in acquiring personal and affective information that is not necessarily evidence-based. In other words, audience participants are interested not only in what they can learn about a topic or issue, but they would like to inform themselves of how others *feel* about those topics or issues (and to share with others how they themselves feel), with a goal of integrating others' values, feelings, or beliefs into their understanding.

Toward Increasing Audience Dialogue at Science Cafés

By breaking out the data in terms of the types of questions asked at Science Café events with specific topic types, we were able to observe shifting trends in how askers' learning goals changed made visible through the types of questions that they were asking.

While audience participants at Science Café events demonstrated similar Information-Seeking question-asking behaviors across all topic types, Challenging Science Cafés demonstrated a significant decrease in audience participants who stepped up to the microphone during panel discussions to answer another audience member's question, either by positing an opinion or sharing their own knowledge on the topic (a non–information-seeking behavior). In what is the largest grouping of Science Cafés (58.54% of all Science Cafés), only three participants engaged in this behavior. This decreased behavior implies a lack of comfort or familiarity with the topics of discussion—when paired with a significant increase in Personal Relevance question types, the implication becomes one of question askers seeking relevance to build comfort. More easily apprehensible or personally-relevant topics, such as those found in the Locally-Relevant Science Cafés might promote easier dialogue between audience participants at Science Café events.

As public events intended as sites of science communication through dialogue. this change in question-asking among audience participants attending Science Cafés discussing more challenging, complex, or abstract topics might present barriers to discussion, relegating the events to transmission-model presentations, where experts are exclusive providers of knowledge and audience participants are receivers of knowledge. It is poignant that, although there was a marked decrease in audience members engaging in dialogue with each other, there was no parallel decrease in other non–information-seeking question-asking behaviors, such as opinion-sharing, or knowledge-sharing directed toward the panelists. Further research would be required to understand if there is a perceptual shift in how audience members view each other as discursive partners as topics of discussion become more complex.

The changes in question-asking among audience participants for different types of Science Café topics indicate that Science Café event attendees' learning goals change depending on the type of Science Cafés that they are attending. Generally speaking, understanding audience behaviors with respect to their learning goals is useful for science centers, museums, or educators hosting Science Café events because event topics can be selected to support those centers' event goals (if any exist). Likewise, science communicators and panelists (or the organizations hosting the events) can be better prepared for the nature of questions likely to be asked given a topic type, or can modify their presentations of material to meet audience learning goals (for example, introducing more opportunities for audience participants to contribute responses to other audience members Science Café events focused upon a Challenging topic).

Recommendations for Future Study

The data collected for this study was collected solely from Science Café events. Further research would be needed to confirm that the participant behaviors observed at Science Cafés translate to non-Science Café learning events, such as panel discussions that do not follow a Science Café structure, or formal presentations followed by question and answer sessions, and that the framework can, in those cases, be applied effectively. It is possible that differently-structured learning events will yield different environments that either encourage or discourage question-asking behaviors. To illustrate event-specific challenges, while there is a lack of research in the area of the nature or content of questions asked at academic conferences, Telis et al. (2019) observed that the social culture and internal factors such as biases at academic conferences affected the participation of women during discussions at panels regardless of their representation within the audience population. They also found that public intervention outside of conference spaces acknowledging under-participation in women can cause an increase in their participation at subsequent events (an effect that can be attributed to changed expectations on behalf of the audience participants). Previous studies have cited similar gender differences in terms of conference question-asking behaviors (Hinsley et al., 2017; Carter et al., 2019; Davenport et al., 2014). It stands to argue that, if contextual factors are influencing *who* among audience participants are engaging in question-asking behaviors, then these factors may also affect the natures of the questions being asked. These factors may encompass speaker delivery, demeanor, and—as indicated in this study—event topic. It is also possible that the different natures of other, non-Science Café informal learning events produce different learning motivations, and therefore different question types and subtypes not captured within a framework developed using only audience data from Science Café events.

In terms of audience context influencing question-asking behaviors, very little demographics data was collected by Science North at the Science Café events researched in this study; however, many audience participants did introduce themselves during their engagements by self-identifying as either experts or non-experts. An interesting future avenue of research would be to analyze these incidences of self-identification to evaluate whether relationships exist between an asker's self-designation as an expert or non-expert and the nature of questions being asked. There is an opportunity here to expand upon Kerr et al.'s work (2007) on the topic of participants self-identifying as experts or non-experts at activities that employ public dialogue about science, technology and medicine.

This study sought to understand the natures of audience questions at Science Café events—understanding the audiences who attend these events allows for these events to be constructed not only in a fashion that encourages question-asking, but that creates a conversational environment that promotes the comfort of all audience members to engage in the activity of question-asking, no matter the question-asker's prior knowledge or overall comprehension of the event topic. Science Cafés as events already serve to break down some barriers to non-expert audiences by virtue of being organized informal events built to answer questions in a dialogic manner in casual settings. Rather than extrapolating from formal education learning frameworks that are built to evaluate the cognitive complexity of question-asking behaviors as a measure of learning success, this framework was grounded in the informal question-asking behaviors that Science Café audience participants already display, allowing us to "meet them where they are," and recognize and support the personal learning goals that motivate them to attend and participate during Science Café discussions. Just as Telis et al. (2019) observed changes in participation behaviors with some public intervention geared toward improving the comfort of conference spaces for women, this study can act as a step toward structuring Science Café events and similar informal public engagement in science events in ways that not only understand their audiences as learners, but that also cultivate these events as spaces that support question-asking for all audience members.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. Example transcripts are included in the supplementary material. For all transcripts and access to the original audio files used in this research, please contact the corresponding author.

AUTHOR CONTRIBUTIONS

NN conceived and developed the framework and performed data analysis. AH verified the analytical methods and results. NN wrote the manuscript in consultation with AH and CB. AH and CB supervised the project. All authors provided critical feedback and helped shape the research and manuscript.

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SUPPLEMENTARY MATERIAL

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Facilitators Improve the Learning Experience of Visitors to a Science Centre

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We studied how interactions with interpretative science centre staff impacts the learning behaviours and engagement levels of visitors who engage with exhibits at Science North (Sudbury, Canada). This study uses the Visitor-Based Learning Framework. The tool consists of seven discrete learning-associated behaviours that visitors show when engaging with exhibits, which are grouped into three categories of engagement: Initiation, Transition, and Breakthrough. These categories reflect increasing levels of engagement and depth of the learning experience. We studied forty-seven Science North exhibits, and 4,835 visitors to analyse the impact of unstructured facilitation in a naturalistic setting. We compared visitor Engagement Levels with and without a facilitator present. We determined that the presence of staff has a statistically significant impact on the percentage of visitors that engage in Breakthrough behaviours. When a facilitator is present, more visitors reach the Breakthrough Level of Engagement ($p < 0.001$). In the second phase of the study, we explored what facilitators do and say through thematic analysis to uncover common patterns of facilitator actions and comments. Our findings showed that facilitators employed strategies and methods that can be grouped in four categories or Facilitation Dimensions: Comfort, Information, Reflection, and Exhibit Use. These dimensions encompass different strategies and techniques of facilitation, that are used in a variety of situations and sequences. Our study goes beyond anecdotal evidence to show that staff-visitor interactions have a positive impact on visitor engagement with exhibits and therefore, potentially on visitor learning from exhibits. Our findings can be used to inform not only training programs but also managerial decisions and considerations around resource allocation. We suggest that facilitators are a fundamental asset for institutions that prioritize visitor engagement, one that should be given top priority when considering areas for investing.

Keywords: free choice learning, science centres and museums, facilitators, visitor learning, science centre staff, science centre, informal learning, visitor engagement

INTRODUCTION

There is no doubt that learning science is not restricted to spaces and contexts traditionally recognized for this function. Terms like "lifelong learning" emphasize that the learning of concepts, methods and scientific thinking must be understood as a long-term process, throughout life, and much broader than the scope of formal education (Aspin and Chapman, 2000; National Research Council, 2009; Falk and Dierking, 2012; 2018). Among the many opportunities to learn science outside of school settings, museums and science centres have a special place because of their potential to provide meaningful and unique experiences to each visitor (Stocklmayer and Rennie, 2017). These learning spaces are considered "informal" and are often described as environments where one can engage in "free-choice learning" (Falk, 2001; Falk and Dierking, 2012). Free-choice learning tends to be non-linear, since it is driven by the learner's intrinsic needs and interests, and involves considerable choice on the part of the learner as to what, where and when to learn (Falk and Dierking, 2000; Falk, 2001). Informal science education environments have important characteristics that shape the resulting learning experience. Land-Zandstra et al. (2020) summarize informal science education as "often based on voluntary participation; connects to personal interests through a learner-centered approach, lacks formal assessment, and provides opportunities for social interactions with other participants." In addition, the informal setting experience mobilizes a particular set of feelings, sensations and situations that are intrinsically linked to the learning process (Falk and Dierking, 2013). Science centre experiences are often developed to consider visitors' previous knowledge and contribute to the making of meaning around science concepts and ideas (Kirchberg and Tröndle, 2012). Scholars in this field widely agree that understanding how people engage in science diverse contexts, such as science centres, "requires pushing the notion of learning science well beyond the limits of cognitive concepts, and reaching into the realms of interest, enthusiasm, motivation, and the social context of learning" (Rennie, 2012, p. 198).

At its most basic level, a science centre visit involves physically interacting with an array of hands-on exhibits, usually as part of a group (family or school for example). Understanding the role of this interactivity in a visitor's learning experience has been investigated since at least the 1990's (Boisvert and Slez, 1995; Serrel, 1997 for example) and many researchers have since explored aspects of exhibit design that optimize visitor interaction that leads to engagement, contributing to the visitor learning experience (Afonso and Gilbert, 2007; Hohenstein and Tran, 2007; Humphrey and Gutwill, 2005; Allen, 2004 to name a few). More recently, researchers are investigating physical interactions with exhibits to more deeply understand how visitors use their bodies to make sense of science concepts and form a science identity [see for example Shaby and Veder-Weiss (2021) for an exploration of embodiment in informal environments].

Many authors and researchers in informal science education recognize that engagement, as influenced by visitors' prior experience and understanding, is key for meaning making and the construction of knowledge in the science centre setting (Kisiel, 2012; Hauan and Kolstø, 2014; Ocampo-Agudelo and Maya, 2021). Barriault and Pearson (2010) for example, developed a framework that links visitor engagement and learning-associated behaviors to the potential learning impact of an exhibit. Their Visitor-Based Learning Framework (VBLF) draws from constructivist and socio-constructivist learning perspectives (Barriault and Pearson, 2010) and provides science centre practitioners with an exhibit assessment tool that is empirically-driven and rooted in science centre visitor observations.

When investigating the visitor learning experience in free-choice environments, the Contextual Model of Learning proposed by Falk and Dierking (2013) is also a helpful theoretical construct. This model states that a museum visit exists and is constructed in the interplay of three contexts: personal, physical, and sociocultural. The socio-cultural context stems in part from the visitor's culture, beliefs and values, along with their previous ideas of what a museum is and feels like, as an institution. Importantly, the museum experience is mediated by micro-sociocultural interactions with others, including members of their group, other visitors, facilitators, or staff (Falk and Dierking, 2013; 2018). It could be argued that, in the informal science setting, facilitators are uniquely situated to engage with visitors by integrating these three contexts through an invitation to explore and discover the physical setting (a whole floor or a single exhibit) and creating opportunities for social interactions that address the personal context and lead to the making of meaning for the visitor (Pattison and Dierking, 2012; Falk and Dierking, 2013). The informal learning setting enables and provides the space for unstructured social interactions to occur, both among individuals in groups of visitors, and between visitors and facilitators (Land-Zandstra, 2020). Researchers in fact suggest that social interaction promotes dialogue and engagement between the visitor and the exhibit (National Research Council, 2009; Jakobsson and Davidsson, 2012; Patrick and Tunnicliffe, 2013).

As visitors' physical interactions with an exhibit are so often facilitated by science centre or museum staff, researchers have explored the role that facilitators play in that experience (Leinhardt et al., 2003; Lindemann-Matthies and Kamer, 2006; Anderson et al., 2002; Mony and Heilich, 2008; Pattison and Dierking, 2012). For science centre and museum practitioners, assessing the direct impact of a facilitator on visitors' engagement with an exhibit could provide empirical evidence on which to base staffing decisions, with the potential to inform facilitator training. Thus, the purpose of this study is to analyse the impact facilitators have on the level of engagement of visitors as they interact with exhibits using the Visitor-Based Learning Framework (Barriault and Pearson, 2010; Barriault and Rennie, 2019). To complement this investigation, we explore the common patterns of facilitator activity in their interactions with visitors.

Visitor-Facilitator Interactions in Museums

Previous studies suggest that visitors have positive feelings about engaging with museum staff (Anderson et al., 2002), and that visitors value interactions with facilitators more than getting information from signs and reading materials (Mony and Heilich, 2008). Furthermore, visitors report that they learn something new more frequently when they interact with facilitators (Lindemann-Matthies and Kamer, 2006). Falk and Dierking (2013) report that "the few studies conducted with casual visitors do suggest that staff positively influence the experience, particularly when they are skilled interpreters, helping to facilitate and make the experience meaningful for visitors" (p. 163). Noticeably, informal or unstructured interactions between facilitators and visitors in museums and science centres encompass a largely unexplored research territory. The majority of studies conducted on visitor-facilitator interactions so far have focused on structured interactions, such as school group tours [Gutwill and Allen, 2012; see Hauan and Kolstø (2014) for a review] or specifically designed and structured programs and exhibit experiences.

Investigations of structured interactions have been carried out extensively at the Exploratorium in San Francisco, where staff facilitate the visitor experience with exhibits or programs designed specifically to encourage inquiry behaviour (Allen and Gutwill, 2009; Gutwill and Allen, 2010; Gutwill and Allen, 2012). More recently, Pattison and Dierking conducted a series of studies exploring unstructured, but controlled, visitor-facilitator interactions. Their research centres mostly on family learning at interactive math exhibits, facilitated by experienced museum educators who are trained in their approach (Pattison and Dierking, 2013; Pattison et al., 2017; Pattison et al., 2018). Specifically, their studies focus on: a. families, b. math exhibits that were intentionally designed to support staff–family interactions through specific "facilitation affordances," and c. experienced facilitators who underwent extra training for these studies (Pattison et al., 2018). While Pattison and Dierking's investigations give very valuable insight into unstructured staff-visitor interactions, their approach is limited in its ability to capture and understand the role of unstructured staff-visitor interactions because of the controlled design of both the exhibits and the facilitator training. There remains a need to study the impact of unstructured facilitator interactions on visitor engagement with exhibits in naturalistic settings, that can be more easily and broadly applied by practitioners in science centres. The Visitor-Based Learning Framework (Barriault and Pearson, 2010; Barriault and Rennie, 2019) is a tool that lends itself to such an investigation.

The Visitor-Based Learning Framework

Although most researchers agree that science centres are rich learning environments, it can be costly and difficult to evaluate the learning experience (Barriault, 1999). By observing visitors and analysing their interactions and conversations, Barriault (1999) and Barriault and Pearson (2010) directly addressed this concern and developed a practical tool based on constructivist learning theories. In the Visitor-Based Learning Framework, the assessment of the learning taking place is not focused on cognitive gains and instead considers the conditions, processes and engagement that are conducive to learning.

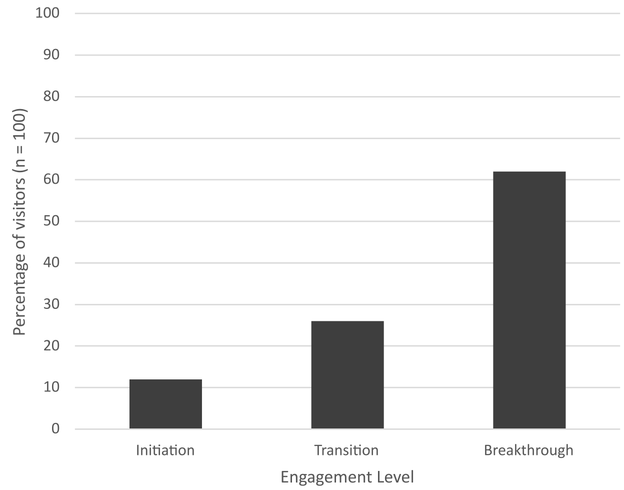

FIGURE 1 | Example of a visitor engagement profile.

The tool consists of seven discrete learning behaviours that visitors show when engaging with exhibits, which are grouped into three categories of engagement (Initiation, Transition, and Breakthrough). These categories reflect increasing levels of engagement and depth of the learning experience, but do not necessarily occur in a linear fashion (Barriault and Pearson, 2010; Barriault and Rennie, 2019). Initiation behaviours happen when visitors take the first steps in engaging with an exhibit but are not completely involved yet. Transition behaviours are characterized by positive body language and outbursts of emotion. They indicate the visitor is comfortable and is able and willing to engage more thoroughly in the activity. Finally, according to Barriault and Pearson (2010) Breakthrough behaviours reflect a commitment on the part of the visitor to fully engage with the learning opportunities provided by the exhibit; Barriault and Pearson (2010) argue that, in this level of engagement visitors recognize the relevance of the activity (and its associated learning gains) to their own personal life. In this category, it is evident that the visitor is making meaning beyond the purely physical interaction: they build on their previous experience and engage in further exploration and inquiry (Barriault and Pearson, 2010). It is important to point out that the goal of the framework is to assess the potential learning impact of the exhibits. The tool does not focus on visitor characteristics nor does it aim to evaluate visitors' knowledge about the science in the exhibit or the issue discussed (Monteiro et al., 2018).

The percentage of visitors that reach each category can be plotted to produce a visual representation of the potential of an exhibit in engaging visitors, called the Visitor Engagement Profile (VEP, **Figure 1**).

This assessment tool was developed empirically in science centres (Barriault 1999; Barriault and Pearson, 2010), has been validated (Barriault, 2014) and is recognized as a standardized way to assess the how effective an exhibit is in engaging visitors in a learning

TABLE 1 | The engagement levels and learning behaviours of the visitor-based learning framework based on Barriault and Pearson (2010).[1]

Engagement level	Learning behaviours
Initiation	1. Doing the activity (in passing or completely, but without further exploration) 2. Observing the exhibit or other visitors engaging in the activity
Transition	3. Repeating the activity to obtain a desired outcome and/or changing variables looking for a difference in outcome 4. Expressing emotional response in reaction to engaging in the activity, including an excited disposition and verbal reference to enjoyment
Breakthrough	5. Referring to past experiences while engaging in activity, including making comparisons and deductions based on observations of similarities and differences 6. Seeking and sharing information, including having conversations with staff or family members, and reading signage 7. Being engaged and involved, including testing variables, remaining on task for several minutes, making comparisons, using information gained from activity

experience (Barriault and Rennie, 2019; see for example; Shaby et al., 2017; Barriault et al., 2011; Harkins and Harlow, 2011; Visscher and Morrissey, 2010; Schliessmann and Ohding, 2009). Most relevant in the context of our study, Barriault and Pearson (2010) posited that, when comparing facilitated and unfacilitated visitor experiences, "the Visitor Engagement Profiles will reflect the role of floor staff in encouraging a higher level of engagement" (p. 104).

Thus, we investigated the impact that interacting with a facilitator has on visitor behaviour and engagement using the Visitor-Based Learning Framework (VBLF) as our assessment tool. We did this in two phases. In Phase 1, we investigated the impact of visitor-facilitator interactions on visitor engagement. To the best of our knowledge, this is the first study that uses the VBLF as a tool to investigate visitor-facilitator interactions to provide empirical evidence of facilitator impact on visitor engagement and thus, potential learning. Our hypothesis is that an interaction with a facilitator at an exhibit will increase the percentage of visitors that reach the Breakthrough Engagement Level. If that were the case, it is reasonable to suggest that the facilitators interact with visitors in ways that encourage the types of visitor engagement that can lead to learning (Barriault and Pearson, 2010; Barriault and Rennie, 2019). Therefore, in Phase 2 we examined the behaviours of facilitators to better understand the results of the first phase of the study and to describe some characteristics of the facilitator-visitor interactions that can influence visitor engagement and learning.

The research reported here aims to provide clear evidence of facilitator impact on visitor engagement and learning with exhibits in a science centre by answering the following research questions:

RQ1: Do interactions with facilitators at exhibits increase the percentage of visitors that reach the Breakthrough Engagement Level as defined by the VBLF?

RQ2: If so, what are the common types of facilitator behaviours or strategies used when interacting with visitors?

METHODS

Research Site and its Facilitators

Science North is the second largest science centre in Canada. It is located in Sudbury, Ontario and opened its doors to the public in 1984. The facilitators in Science North, affectionately known as Blue Coats, are trained to be: "Caretakers" (take care of visitors, ensure surroundings are clean are safe), "Ambassadors" (represent the attributes of the organization, act as a role model to visitors and peers), "Trouble-shooters" (use problem solving skills, are flexible and adaptable, ensure visitors' comfort), "Initiators" (actively engage visitors in science activities), "Scientists" (involve people in the scientific process, eliminate science intimidation, create and promote a sense of wonder), and "Entertainers" (make science fun and understandable through their energy and enthusiasm, be adventurous and spontaneous) (Bray et al., 2011, p.78). These six attributes are known as the "Blue Coat Standards of Excellence."

Science North's exhibit evaluation and research team has years of experience applying the VBLF (Barriault and Pearson, 2010) to assess and improve their exhibits and enhance the visitor experience. Since 2008, the science centre has video recorded and analysed video data to produce Visitor Engagement Profiles for hundreds of individual exhibits. The VBLF and VEP for exhibits are part of the institution's formal exhibit evaluation practices and have become part Science North's organizational measures of success (Barriault et al., 2011; Monteiro et al., 2018).

Pre-Existing Data and its Analysis

The video data used in our study were previously collected, analysed and coded by Science North researchers using the Visitor-Based Learning Framework (Barriault and Pearson, 2010; Barriault and Rennie, 2019). As the video-recordings of visitors were viewed, research staff from Science North coded visitor behaviours and dialogue using the VBLF as the coding protocol. **Table 1** shows the VBLF as it appears in Barriault and Pearson (2010), with Engagement Levels and descriptions of the Learning Behaviours [the reader is directed to Barriault and Pearson (2010), to see the full framework and details of coding protocols]. The coded data include the number of visitors who reach Initiation, Transition and Breakthrough levels of engagement for each exhibit. Importantly for this study, the presence of a facilitator, defined as an instance where a facilitator interacts with one or more visitors at an exhibit, was also coded by Science North researchers. During data collection, Science North staff record the interactions of at least 100 visitors at each exhibit. Ethics protocols are always in place for all the recordings and follow the general recommendations of Gutwill (2003).[1]

Our raw dataset consists of approximately 25 h of coded video and audio recording from the past 12 years (2008–2020), of about 15,000 visitors interacting with 137 exhibits. This vast dataset is a rich source of insight into visitor-facilitator interactions, which had not yet been examined for that purpose. Even though the facilitators were always aware that the exhibit was being recorded to evaluate its learning potential (and that they were consequently recorded along with it), these coded data sets provide an excellent sample of "natural" (as opposed to staged) visitor-facilitator interactions for two reasons: 1. recordings were not done to evaluate individual facilitators, giving them no reason or incentive to perform a certain way; and 2. according to Science North's research team, facilitators have become familiar with the research activities at the science centre and over time no longer behaved differently as facilitators in the presence of the camera (A. Henson[2], personal communication, June 24, 2020). Therefore, these videos recorded interactions between facilitators and visitors that are as close as possible to how they occur spontaneously and naturally in a science centre setting.

DATA SELECTION

Phase 1 – Impact of Facilitation on Visitor Engagement

The aim of this phase is to investigate the impact of visitor-facilitator interactions on visitor engagement. Of the 137 exhibits that had been previously recorded, coded and analysed, we selected the exhibits that had at least three facilitator interactions in their recorded data, to have a representative sample of visitor-facilitator interaction, and to avoid overestimating the interaction's impact. It is important to note that the research staff at Science North estimate that when exhibits are being recorded, facilitators interact with less than 5% of visitors, perhaps to avoid interfering with the exhibit's performance as it is being recorded (A. Henson[2], personal communication, June 24, 2020). Therefore, if an exhibit's data contains fewer than three facilitator interactions, the engagement levels with a facilitator would be determined by that one or two interactions, which could skew the sample and misrepresent the impact the interaction has on the exhibit's VEP. With this criterion of at least three facilitator interactions in the recorded data of an exhibit, our final data sample is comprised of 47 exhibits, and 4,835 total visitors.

To determine if an interaction with a facilitator increases the percentage of visitors reaching the Breakthrough Level of Engagement at an exhibit, we divided all the visitors from all selected exhibits into two groups: those who interacted with a facilitator (with facilitator, n = 439) and those who did not (without facilitator, n = 4,396). We determined the percentage of visitors that reached each Engagement Level (Initiation, Transition, Breakthrough) for each group (with a facilitator, without facilitator).

Phase 2 – Facilitator Strategies and Techniques

In this phase we examined the verbal and physical behaviours of facilitators to identify and to describe the common activities of the facilitator interactions. We employed qualitative data analysis in the form of emergent patterns or thematic analysis (O'Leary, 2015) of facilitator behaviours in the interaction. We first reviewed all available video from the exhibits studied in Phase 1. Using DaVinci Resolve software, we created separate video segments that showed visitors interacting with facilitators. Each segment begins when the facilitator walks into the space of the exhibit being recorded, or is brought there by a visitor, and ends when the facilitator walks out of that space. This created a pool of 227 visitor-facilitator interactions (approximately 4 h of footage) which were downloaded as 227 individual segments into NVivo12 for analysis. We applied the protocols of systematic thematic analysis, as described by Braun and Clarke (2006) to our data analysis as follows: The first author reviewed and familiarized themselves with the data while making initial notes and memos about recurring patterns in facilitator behaviour (actions and dialogue), generated initial codes and, began to categorize them into themes. The research team then discussed the emergent codes and themes at length to minimize observer bias, and to verify that the themes that emerged were representative of the data we observed (Braun and Clarke, 2006; Charmaz, 2006). As the research progressed, we systematically identified and compared the different categories of behaviours. We also conducted several rounds of observations to further explore and refine the emergent categories, to further refine and name themes, and to ensure we achieved theoretical saturation (Braun and Clarke, 2006). Since the researchers are experienced facilitators, they consciously brought this perspective to the data analysis when coding facilitator behaviours.

RESULTS

Phase 1 – Impact of Facilitation on Visitor Engagement

Figure 3 shows the overall Visitor Engagement Profile for all 47 exhibits combined, with and without facilitator interaction. Facilitator interactions represent between 3 and 27% (Mdn = 6%) of all visitor - exhibit interactions in this data set of 47 exhibits.

As shown in **Figure 2**, there is a difference between the two groups for the percentage of visitors in each Engagement Level. For visitors who interacted with a facilitator, the percentage who only reached Initiation is lower (21.4%) than for visitors who did not interact with a facilitator (42.5%). The percentage of visitors who did not go beyond Transition is virtually the same (28.4 vs. 27.6%) for the two groups. Finally, the percentage of visitors who

[1]Table was used with permission from Barriault and Pearson

[2]Senior Scientist, Science Centre Operations and New Audiences, Science North

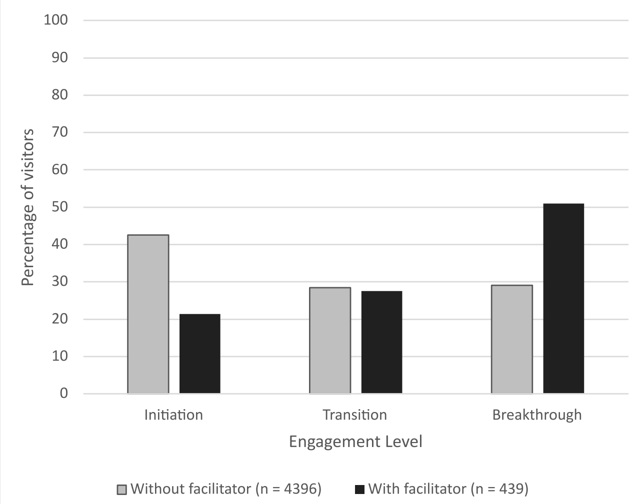

FIGURE 2 | Overall visitor engagement profile, with and without facilitator interaction, for 47 exhibits.

reached Breakthrough is higher (51.0%) for the visitors who interacted with a facilitator than for visitors who did not (29.1%).

The level of engagement is associated with the presence of a facilitator, that is, more visitors reach Breakthrough when a facilitator is present. This association is statistically significant, $\chi^2(2, N = 4{,}835) = 105.81$, $p = 1.06 \times 10^{-23}$ with a moderate size effect (Cramer's V = 0.15). Furthermore, there is a moderate positive correlation of 14% ($\tau_b = 0.14 \pm 0.06$, $p = 2.60 \times 10^{-24}$) between the presence of a facilitator and the level of engagement.

Phase 2 – Strategies and Techniques

Four themes of facilitator interaction behaviours emerged from the data: Comfort, Information, Reflection and Exhibit Use. We called them "Facilitation Dimensions" because these actions and comments encompass different strategies and techniques of facilitation.

As a representative example of our thematic data analysis, **Table 2** shows a transcript of an interaction between a visitor and a facilitator, with the corresponding codes. In the exhibit studied, visitors use a spinning dial to control the speed of a video of lightning, including the possibility to see it in slow motion. The interaction starts when a visitor, who is interacting with the exhibit, speaks to a facilitator standing a short distance behind.

Tables 3–6 show representative examples of the Facilitator Behaviour for each Facilitation Dimension, including descriptions, and representative examples from the data.

The Comfort Facilitation Dimension describes facilitator behaviours that are welcoming and encouraging to the visitors, making the interaction with the exhibit more pleasant. **Table 3** shows the Facilitator Behaviours for this Facilitation Dimension.

The Information Facilitation Dimension includes strategies related to the science content of the exhibit and other information related to this content. **Table 4** shows the Facilitator Behaviours for this Facilitation Dimension.

The Reflection Facilitation Dimension encompasses the strategies and techniques used by facilitators to help visitors fully engage with the exhibit, through reflection and making connections. **Table 5** shows the Facilitator Behaviours for this Dimension.

Finally, the Exhibit Use Facilitation Dimension includes all strategies and behaviours related to exhibit use, including instructions and tips on how to use the exhibit. **Table 6** shows the Facilitator Behaviour for this Dimension.

Table 7 shows the frequency of use of Facilitation Dimensions and Facilitator Behaviours. Frequency is the number of interactions in which strategies from each Dimension were used, not how many times that strategy was used in the same interaction. For example, in the transcript shown in **Table 2**, the facilitator uses encouraging language twice, laughs twice, calls attention to a phenomena once and gives context and explanation once. When counting for frequencies, this amounts to one instance of "Encouraging language," one instance of "Laughter, joy," one instance of "Calling attention to phenomena" and one

TABLE 2 | Visitor-facilitator interaction transcript with assigned facilitator codes and dimensions.

	Transcript of visitor-facilitator interaction	Facilitator codes (Dimensions)
Visitor	(turns to facilitator, pointing at exhibit) Look at that, it's an explosion!	
Facilitator	Isn't it cool? It is kind of like, kind an explosion, right? It's like all this electricity goes just kkjjjj (explosion onomatopoeia)	Encouraging language (Comfort)
Visitor	(keeps spinning the dial) Wiiiii!!	
Facilitator	(laughs)	Laughter, joy (Comfort)
Visitor	(ininteligible)	
Facilitator	Did you see the one that comes from the bottom? (points at exhibit) Let me see if I can find it… (spins the dial) Here we go, this one… It actually comes from--	Calling attention to phenomena (Reflection)
Visitor	--from the ground?	
Facilitator	From the ground… which is cool, right?	Encouraging language (Comfort)
Visitor	Yeah	
Facilitator	How does that happen? There are charges, electrical charges on the ground, often in something like a tower or a tall building, or something like that, like the CN tower… the charges build up on that and they go up trying to find an opposite charge and it finds it inside the cloud	Giving context and explanation (Information)
Visitor	That's the big explosion, right?	
Facilitator	(nods) It's really cool, right? (laughs)	Laughter, joy (Comfort)
Visitor	(nods and leaves)	

TABLE 3 | Comfort facilitation dimension.

Comfort facilitator behaviour	Representative examples
Encouraging language	"Great job!" "That's not quite right, keep trying!"
Welcoming (greeting, inviting visitor to use the exhibit, general introductory questions)	"Hello, how are you today?" "Would you like to spin the wheel?" "So, are you any good at this?"
Laughter, joy (verbal and non-verbal displays of joy)	Laughing out loud Smiling
Focuses on visitor (body language that conveys they are paying attention to the visitor)	Looking people in the eye Facing people when talking

TABLE 4 | Information facilitation dimension.

Information facilitator behaviour	Representative examples
Giving explanation only	"The water is evaporating. . ." "This would be a lot easier for an elephant, because they have so many muscles in their trunk"
Giving context only	"The arctic is here (points at map) and we are in Sudbury, here" (points at map)
Giving explanation AND context	"There are electrical charges on the ground, often in something like a tower or a tall building, or something like that, like the CN tower. . . the charges build up on that and they go up trying to find an opposite charge and it finds it inside the cloud"
Tells a story	"So, what's happening with this frog is that it's very sick, so what we've been noticing. . . because this frog lives in Panama, very far away, and they live in mountain tops. . . so, they were disappearing. . . so what they (scientists) did, was they started analysing the frog skin, so now they found that they had a fungus"
Explaining how the exhibit works	"There is an infrared camera there, which allows us to see the heat, things that are cold are blue, things that are hot are red and white"
Fun facts	"An elephant trunk has up to 40,000 muscles!"

TABLE 5 | Reflection facilitation dimension.

Reflection facilitator behaviour	Representative examples
Making connections	"Do you guys want to see why you're not quite as strong as an orangutan? Follow me!" (takes them to another exhibit) At an exhibit which shows real-time thermal imaging of the visitor, the facilitator brings out a snake and says "that this is how they see their prey"
Calling attention to phenomena	"The marbles near the centre go faster"
Proposing a challenge or experiment	"You can try and build something" (Visitor 1 interacts with the exhibit, then visitor 2 interacts with the exhibit) "How about together?"
Inviting reflection	"Why do you think we take eggs from robins' nests?"
Asking a trigger question	"So, how many eggs do you think she laid" (To a girl looking into a microscope) "Do you know what you're looking at in there?"
Asking the visitor for a guess or a hypothesis	"If I were to take an egg from a robin and give it to either a tomtit, a dunnock, or a starling, which one do you think would make the best adoptive parents? . . . Why?"

instance of "Giving context and explanation". Likewise, this amounts to one instance of the Comfort Dimension, one instance of the Information Dimension and one instance of the Reflection Dimension.

DISCUSSION

The results show that the presence of a facilitator increases the percentage of visitors who reached Breakthrough levels of engagement as described in the Visitor-Based Learning Framework (Barriault and Pearson, 2010; Barriault and Rennie, 2019). This finding is statistically significant. In addition, the percentage of visitors that only reach Initiation levels of engagement is lower with a facilitator and this finding is also statistically significant. Lastly, the percentage of visitors reaching Transition levels of engagement is almost the same with and without facilitator interaction. Therefore, it can be suggested that the increase in the percentage of visitors that engage in Breakthrough level behaviours comes from the reduction in the percentage of visitors that engage no further than Initiation. These findings, though preliminary, are supported by constructivist and socio-cultural models of learning (Falk and Dierking, 2013, 2018), in which learning is recognized as active, highly contextual and social in nature (Hein, 1998; McCallie et al., 2009; National

TABLE 6 | Exhibit use facilitation dimension.

Exhibit use facilitator behaviour	Representative examples
Showing how to use the exhibit	Physically demonstrating how to use the exhibit
Telling how to use the exhibit	"All you do is you squeeze the level and see how strong you are"
Insight into exhibit use	"You can also try this, it's fun!"
	"For one of them, I'll give you a hint, you have to step back from the table"
Using the exhibit along with the visitor	Being player 2 on a two-player exhibit
Providing technical assistance	Rebooting the system for an exhibit that has a projector and computer system

TABLE 7 | Facilitation dimensions and facilitator behaviours in order of frequency of use.

Facilitation dimension	Frequency	Facilitator behaviour	Frequency
Comfort	124	Encouraging language	59
		Welcoming	53
		Laughter, joy	33
		Focuses on visitor	18
Exhibit use	111	Showing how to use the exhibit	59
		Telling how to use the exhibit	28
		Insight into exhibit use	19
		Using the exhibit along with the visitor	18
		Providing technical assistance	8
Information	92	Giving context and explanation	45
		Giving explanation	24
		Giving context	17
		Tells a story	15
		Explaining how the exhibit works	9
		Fun facts	6
Reflection	67	Making connections	27
		Calling attention to phenomena	18
		Proposing a challenge or experiment	15
		Inviting reflection	15
		Asking a trigger question	14
		Asking the visitor for a guess or a hypothesis	11

Research Council, 2009; Jakobsson and Davidsson, 2012; Falk and Dierking, 2013, 2018).

The qualitative phase of this study provides further insight into the behaviours and strategies of facilitators that may have contributed to this increase in visitor engagement with exhibits. Our thematic analysis of facilitator behaviours revealed an initial framework that describes the strategies facilitators used when interacting with visitors and consists of four Facilitation Dimensions: Comfort, Information, Reflection, and Exhibit Use. We would like to emphasize that our proposed framework of Facilitator Dimensions is a preliminary categorization of common verbal and behavioural activities displayed by the staff in our data set. Although a more in-depth analysis of facilitator-visitor-exhibit interactivity is needed to draw causal relationships between specific facilitator actions and increase in visitor Engagement Levels (Barriault and Pearson, 2010; Barriault and Rennie, 2019), we argue that Facilitator Dimensions are an important contribution to understanding the impact facilitators have on the visitor learning experience with an exhibit.

In our study, the Comfort Dimension is the most frequently used, which may be unsurprising given the importance of welcoming visitors into the exhibit space. If visitors feel uncomfortable, unsafe or unwelcomed, they will likely not engage with exhibits (Barriault and Pearson, 2010) and learning can become challenging because people's basic needs are not being met (Maslow, 1943). The importance of Comfort for facilitator behaviours is supported by previous research that demonstrated that for families, a positive experience with facilitators was associated with a safe, comfortable, and welcoming environment (Brown et al., 2019). By using strategies in the Comfort Facilitation Dimension, we argue that facilitators are showing respect and care for their visitors.

The second most frequently used Facilitator Behaviour Dimension is Exhibit Use which includes actions like explaining how to use an exhibit, using the exhibit alongside the visitor, giving them a tip or a hint, or providing technical assistance. Even considering that our study is independent of individual exhibit characteristics, physically interacting with, or operating the exhibit, plays a key role in the science centre learning experience (Afonso and Gilbert, 2007; Hohenstein and Tran, 2007; Humphrey and Gutwill, 2005; Allen, 2004). When applying strategies from Exhibit Use Facilitation Dimension, we suggest that facilitators are providing added value for visitors, by helping them interact with the exhibit as the basic science centre experience (by providing technical assistance or explaining how to do it) and to go beyond the obvious affordances (by providing tips, hints, or different ways to engage with the exhibit), which may lead to visitors spending more time with the exhibit, and having a deeper, more meaningful experience.

The Information Facilitation Dimension describes facilitator behaviours that give visitors more information about the science content of the exhibit, which it can be argued is the typical and expected behaviour of facilitators in science centres and museums (King and Tran, 2017). Delivery and timing are important aspects of the Information Dimension because facilitators should be able to provide information in a way that is not too didactic or expository, and they should also be able to identify when would be the best moment to interact with visitors who are engaging with an exhibit (Brown et al., 2019). Experienced facilitators can determine the best way to engage with each visitor, as this is learned with practice. Learning how to actively listen, observe and respond to visitors in a way that maximizes their opportunities for learning is a sizable task for facilitators (Ash et al., 2012; Patrick, 2017a). The Information Facilitation and the Comfort Dimensions together emphasize the importance of listening, observing and responding to visitors during an interaction.

The Reflection Facilitation Dimension includes facilitator strategies that help visitors fully engage with the exhibit, by inviting (but never ordering or insisting) visitors to reflect on proposed hypotheses, to make connections and to engage in critical thinking. In our study, the Reflection Facilitation Dimension was used the least frequently. We suggest that this may be because these strategies can only be applied when the visitor is already invested in the exhibit and indicates that they are open to delving deeper into the subject, to start thinking about the "why" instead of the "what". Exhibits allow visitors to apply their knowledge and make some connections with their prior knowledge (Kisiel et al., 2012; Hauan and Kolstø, 2014; Ocampo-Agudelo and Maya, 2021), and facilitators can provide opportunities to engage in higher order thinking skills such as those identified by Bloom (1956). Our analysis helped demonstrate that interacting with a facilitator can provide opportunities to "critically evaluate the ideas presented, draw connections among ideas and conjecture, and further investigate phenomena and ideas" (Bloom, 1956, p. 200). Various chapters in Patrick (2017a) underscore this reflection role of facilitation and the importance for informal science educators to be proficient in this skill.

We suggest that these Facilitation Dimensions should all be used in combination to provide a richer learning experience for visitors. In other words, facilitators should apply many different strategies, in a variety of sequences, tailored to each visitor and exhibit. Effective facilitation requires the ability to recognize the visitor's readiness to learn and respond accordingly and in a flexible way (Ash et al., 2012). The Facilitator Dimensions proposed in this study can be understood as guidelines for the initial training of science centre and museum facilitators as they gain experience at engaging visitors with exhibits, and can encourage facilitators to reflect on their practice. Patrick (2017b) promotes reflection as a key component of an informal educator's professional growth and recommends asking themselves questions about their practice such as: "Did I take the time to respond in a meaningful way?"; "Did my response foster a desire in the visitor to find out more information"; "Did my response reflect my knowledge of the subject" and "Will my work with visitors aid them in constructing knowledge?" (Patrick, 2017b, p. 47). The Facilitator Dimensions of our study align with the reflection questions and can provide practical guidance to improve practice.

Importantly, our findings from both Phase 1 and Phase 2 support what other researchers and practitioners have observed with respect to facilitator behaviours. Pattison and Dierking (2013), Pattison et al. (2017) identified five facilitation strategies that have some commonalities with our Facilitation Dimensions. For example, Pattison et al. (2017) found that, when using "Orient" strategies, the facilitator provides visitors with an overview of the exhibit and guidance on how to begin the activity, which overlaps with our Exhibit Use Dimension. Pattison et al. (2017) "Challenges" facilitator behaviour, where the facilitator presents challenges to solve or complete using the exhibit, is encompassed in our Reflection Dimension. Our Information Dimension includes the facilitator behaviour that Pattison et al. (2017) refer to as "Provide Explanations." Finally, Pattison et al. (2017) "Show Appreciation" (congratulating, encouraging or praising visitors) and "Establish Visitor Ownership" (encouraging and supporting visitor control, leadership and agency during the experience) facilitator behaviours are both included in our Comfort Dimension. The series of studies by Pattison and Dierking's (2013), Pattison et al. (2017), Pattison et al. (2018) and our present study focus on unstructured interactions between facilitators and visitors. It is therefore not surprising that there is a great deal of overlap between the facilitation strategies they have identified and the four Dimensions that emerged in our study. These commonalities further validate (Pattison and Dierking's, 2013; Pattison et al., 2017; Pattison et al., 2018) findings and strengthen the authenticity (O'Leary, 2015) of our study. However, the main difference between these investigations, and the contribution of our research, is that our Facilitation Dimensions emerged from the data in a "naturalistic" science centre setting, while in Pattison and Dierking's (2013), Pattison et al. (2017), Pattison et al. (2018) studies, the facilitation methodology and exhibits were iteratively developed and tested to support facilitation. Our study's naturalistic setting and its findings are relevant for science centres that do not have the resources to engage in extensive, iterative facilitation and exhibit design, as those employed by Pattison and Dierking's (2013), Pattison et al. (2017), Pattison et al. (2018). In addition, these Facilitation Dimensions emerged from science centre data collected over 12 years, which included all types of exhibits, and were not limited to specific topics, while Pattison and Dierking's series of studies focused on exhibits tailored for facilitation research and mathematical topics specifically.

The Facilitation Dimensions also unsurprisingly reflect Science North's "Blue Coat Standards of Excellence," as described by Bray et al. (2011). Being "Ambassadors," "Initiators," and "Caretakers" aligns with the Comfort Dimension of Facilitation and may be attributable to the high frequency of such facilitation behaviours in our sample. "Trouble-shooting" and "Initiating" are actions that are reflected in the

Exhibit Use Facilitation Dimension, ensuring that visitors can operate and interact with an exhibit. Being "Entertainers" requires strategies from different Dimensions: the behaviours from the Information and Reflection Dimensions aid the visitors in making meaning of the science, which combined with the strategies from the Comfort Dimension make the experience fun and enjoyable. Finally, being "Scientists" relates to the Information Dimension, by helping the visitor get involved in the scientific process and promote curiosity, for example sharing stories or fun facts. Investigating the relationship between Science North's Blue Coat Standards of Excellence, their facilitator training, and our Facilitation Dimensions could inform future training programs.

Implications for Practice

Our study goes beyond anecdotal evidence to clearly show that visitor-facilitator interactions have a positive impact on visitor engagement, as defined by Barriault and Pearson (2010) Visitor-Based Learning Framework, when they interact with exhibits. Facilitators are a fundamental asset for science centres and museums and should be given top priority when considering areas for investing. As science centres and museums strive to remain relevant and fiscally responsible, it is crucial to know the tremendous value facilitators bring to achieving institutional education missions. We suggest that the Facilitation Dimensions can be used to inform an institution's facilitator training programs, and be part of assessing facilitator abilities to promote visitor engagement.

This study certainly opens the doors for further research in the field of science centre and museum visitor studies. As mentioned, future studies examining the relationship between training at the study site and our Facilitation Dimensions would be a valuable contribution to the field and one that we intend on pursuing. Future research could also consider investigating what types of exhibits benefit most from facilitation strategies. Some authors have discussed that facilitator interaction might be unwelcome and staff might interfere with visitor learning (Marino and Koke, 2003; Pattison et al., 2018). Understanding this aspect of unstructured interactions should be further explored, since knowing if and when facilitators should engage with visitors would be as valuable as knowing how. Finally, including other research sites from different science centres and museums would contribute to strengthening the validity and reliability of the current findings. It is clear however that, through intentional and purposeful social interactions, facilitators turn museums and science centre exhibits from mere curiosity cabinets into meaning-making experiences that can engage visitors in science learning.

DATA AVAILABILITY STATEMENT

The compiled data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

CB, PM, and SM contributed to the conception and design of the study. KP collected and coded the data. SM organized the database, performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Evaluating the Impact of a Comprehensive Canadian Science-Art Residency Program on the Participating Scientist, Artist and the Public

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Science-art residencies can provide opportunities for insightful cross-disciplinary collaborations, science communication, and engagement with the general public. Currently, there are few formal ways for artists and scientists to collaborate in Canada, and even fewer publications on how these experiences can impact learning in informal settings. Art the Science (a Canadian non-profit organization facilitating cross-disciplinary relationships between artists and scientists) piloted a comprehensive multiphase science-art residency program. Phase 1 informed the artist's work through a full-time experience in a scientific laboratory at an academic institution, Phase 2 showcased the artist's final artwork, Between the Sand at an off-campus local community event, and Phase 3 published an interactive online version of the work for global exhibition. Residency evaluation in each phase was conducted through the use of qualitative and quantitative methods, including interviews, concept mapping, video diaries, and surveys. The artist, scientist and lab members gained new perspectives and inspiration about their respective fields. The artist was able to incorporate theories and processes from the research group into their artistic practice. On the other hand, the scientist saw renewed enthusiasm and curiosity within their research lab, and the lab members reported new ways of thinking about how to communicate their research. Both exhibitions proved to be engaging informal learning experiences for 66.2% of survey participants, and revealed several major learning themes. Despite promoting both events as artwork exhibitions, 79.2% of survey participants considered Between the Sand as both an artwork and a science communication product suggesting that science-based art may have the potential to communicate science, even when it is not presented as a science communication effort. Public responses revealed that public perception of funding is not skewed to either discipline and instead seems to call upon both science and arts grants to fund such interdisciplinary initiatives. Providing comprehensive artist residencies in science labs may have a valuable impact on everyone involved: the artist, the research group, and the public.

Keywords: science-art, residency, science communication, collaboration, cross-disciplinary, SciArt

INTRODUCTION

Arts-based initiatives are growing as a favoured approach for science communication in formal and informal settings for the general public (Root-Bernstein et al., 2011). Part of the reason may be due to the nature of how art and culture can connect with people in ways that science cannot do alone (Van Riper, 2003; Kaiser et al., 2014). By reshaping narratives and allowing for different mediums of expression, art is not simply a vehicle for communication and understanding. It fosters a space that encourages questions, discussions, and actions around important societal issues, such as the case with climate change (Galafassi et al., 2018). Art can help facilitate storytelling, knowledge exchange and communication which is deeply needed for adults who spend most of their life outside the formal learning environment (Falk and Dierking, 2019). While the art and science culture (in terms of initiatives, programs, and experiences) in Canada has not advanced as far as that of the United States, United Kingdom, Europe, or Australia, the movement is steadily growing and supporting a space for science-art partnerships and experiences (Zaelzer, 2020).

Interactions between art and science can take many forms and are not limited to collaborations like artist residencies, exhibitions, and outreach events. In fact, the interface between these two disciplines garners many labels including ArtScience (Schnugg, 2019), A&S (Sleigh and Craske, 2017), science-art, SciArt, ArtSci, Sci + Art, STEAM (Science, Technology, Engineering, Art and Math), and Science*Art (Stevens et al., 2019). There are also specific practices such as "BioArt", which use techniques and tools in science to make art with the intention of challenging science (Sleigh and Craske, 2017), as well as domains dedicated to the link between art, technology, culture, and society (e.g., Ars Electronica, Milieux, MIT-ADT).

Most notably, the term "SciArt" has been growing since the beginning of the 21st century and continues to be used increasingly on social media (for example, #SciArt and #SciArtTweetStorm on Twitter) and in popular science magazines (former Symbiartic blog on Scientific American). It is also worth noting that the term gained significant momentum thanks to branding of the Wellcome Trust's "Sciart" programme (in the United Kingdom) which provided grants for projects at the intersection of art and science in the late 90s to the early 2000s (Glinkowski and Bamford, 2019). While science communicators and many who practice or work in between the disciplines of art and science may celebrate this term, some hold the opposite disposition, expressing disdain for a branding label that limits and segregates artists by using the visual arts in service for the sciences (Sleigh and Craske, 2017).

If we are to truly foster meaningful relationships between artists and scientists, it is important for both disciplines to be valued. While art can be a communication vessel for science, it can go far beyond this to create discussion, to challenge, to entertain, and to inspire. Including art in science communication or science engagement initiatives is certainly valuable, however we argue that scientists and science communicators should recognize that the art-science interface can and does go beyond simply communicating science to public audiences.

Artist residency programs typically invite artists and other creative professionals to step away from their usual work environments and into a space (usually within an institution) for some time to reflect, do research or produce art. Residencies vary from place to place, with some having a clear focus on the collaboration process, while others offer opportunities to create new artwork based on their experience (Schnugg, 2019). These experiences can provide opportunities for cross-disciplinary collaboration between artists and scientists and can take place within organizational structures (e.g., universities, research centres, companies). Some notable international artist residencies at scientific institutions include Arts at CERN and SymbioticA. In Canada, there have been a handful of artist residencies in dedicated scientific spaces, including Perimeter Institute, University of Guelph (School of Environmental Sciences), Ayatana, Convergence Initiative, the MOCA/OSC residency (Museum of Contemporary Art and Ontario Science Centre) and SNOLAB.

While cross-disciplinary collaborations and programs are increasing, documentation and evaluation of such projects is sparse, and perhaps for good reason. There is no doubt that there is an interest in art-science projects from diverse disciplines, however the outcome can be challenging to evaluate. It can also be difficult for either the artist or the scientist to get recognition for their contribution in their own discipline, and there are barriers to integrate projects within their disciplinary careers (Schnugg, 2019). Additionally, there may be other problems that arise, such as who is responsible for the evaluation, what the purpose of the evaluation is, as well as the availability of time and resources to conduct it.

Arguably the most thorough and large-scale evaluation of science and visual art collaborations is the Wellcome Trust's Sciart programme which spanned a decade from 1996–2006. It supported 118 projects amounting to nearly £3 million in grants with the primary intention of fostering interdisciplinary practice in art and science and engaging the public (adults) in the biomedical sciences. The evaluation consisted of case studies, interviews, surveys, audience tracking, and focus groups to determine emerging themes. Overall, the Sciart programme received mostly positive feedback from artists, scientists, and the general public. Interesting themes that emerged from the evaluations included: 1) Some artists reported an improvement of career opportunities, as they were able to elevate their profile and secure exhibiting or commissioning opportunities; 2) Most scientists reported an improvement in their communication skills and felt more comfortable engaging with the public, and 3) Art opened the scientific practice to a broader audience and made science more accessible. However, the collaborations did not go without challenges. Some artists felt they were more involved than their scientist collaborators, while some scientists felt it was difficult to justify such interdisciplinary collaborations that did not contribute directly to advancing their discipline (Glinkowski and Bamford, 2019).

Examples of enhanced public engagement through art and science collaborations have also been documented through science outreach programs (Drumm et al., 2015) and festivals (Beakerhead, 2017; Rosin et al., 2019). In addition, fields such as environmental science and ecology have seen an increase in support for arts-based initiatives to promote awareness and discussion around climate change and the environment (Galafassi et al., 2018; Stevens et al., 2019; Brault, 2020).

Other approaches have also been used to evaluate or explore art and science initiatives. For example, to better understand the artist and scientist collaboration process, Halpern (2011) provided prompts about the boundaries of art and science to artist and scientist pairs who were then observed on how they engaged with their tasks. Interestingly, other research groups have gone beyond traditional qualitative measures of evaluation (such as interviews and focus groups) to create a new psychosocial framework to measure the aesthetic experience of art-science works, which aims to provide a deeper examination of what specifically occurs at the intersection of art, science, and the public (Muller et al., 2015).

Comprehensive evaluations that include an assessment of the process of art and science collaborations, as well as their impact on public engagement with science, remain low in number. Furthermore, much of the current research and reporting comes from the United Kingdom (Drumm et al., 2015; Glinkowski and Bamford, 2019), Europe (Schnugg, 2019), Australia (Muller et al., 2015) and the United States (Rosin et al., 2019). While there are Canadian art and science initiatives, few have the capacity to implement a formal evaluation. Some question the need for formal evaluations given their contexts, such as galleries and maker/creative spaces where informal feedback (short surveys or speaking to clients) is sufficient for improving future programming (Lau, 2016). However, the art and science (or science-art) culture is growing in Canada through aforementioned organizations and programs/initiatives. It is therefore becoming more important to document, assess, and report on the processes, impacts and ultimate value of such art and science initiatives.

Art the Science (ATS) is a Canadian non-profit organization facilitating cross-disciplinary relationships between artists and scientists to encourage scientific knowledge exchange with public audiences through artistic means. ATS developed a three-phase comprehensive science-artist residency program designed for research institutions (e.g., academia, government) and their scientific researchers. The goal of the residency is to help bridge the gap between research scientists in academic settings, artists interested in science, and the public, who typically have very little access to scientific research. The residency enables the artist to expand their practice in a scientific environment giving the artist access to scientific methodology, tools and concepts often not accessible to artists. The artist has an opportunity to learn and hone novel scientific methodologies, which they can apply in other areas of their work. Finally, by fully integrating into the research group on a full-time basis for several weeks, the artist gains a valuable network of scientists which can lead to opportunities in other research groups.

The research group has an opportunity to view their work in a different light by hosting someone from a different field of expertise. Interactions with the artist may lead the scientists to new perspectives and novel paths of discovery. In addition, artwork created by the artist during the residency will help the research group share elements of their science in a new way with public audiences.

For members of the public, the benefits from this residency are twofold. One of the phases of the residency provides an opportunity for the local community around the institution to engage with the scientist, the artist, and the artwork. The other phase engages the global community at large via an online interactive artwork hosted in Art the Science's online Polyfield Gallery. An online experience, when developed with accessibility in mind, has a much greater reach than an exhibition on gallery walls. The interactive component allows for exploration and engagement.

An environmental engineering research laboratory at Queen's University in Kingston, Ontario, Canada was selected because Dr. Kevin Mumford (henceforth "scientist") expressed interest in exploring creative initiatives with his research group. The group's research focuses on understanding the trajectory of hazardous chemicals when they are discharged into the environment, as well as the remediation of contaminated sites. The group's research projects range from experiments that mimic how liquids and gases move through porous mediums to computer models of those processes.

To pilot the residency program, Art the Science recruited Owen Fernley (henceforth "artist"), an artist who has previously exhibited work with Art the Science. The artist uses creative coding to create artworks. Therefore, his artistic practice complemented the computer modelling research in the scientist's laboratory and provided the artist with a wide range of ideas and data to work with for his creative coding practice. The artist was also recruited to pilot the residency because he had formal training in science prior to becoming an artist, which allowed Art the Science to determine how much the artist relied on his training to navigate a scientific field that was novel for him. The scientist provided in-kind support as well as an artist honorarium for the residency which the artist donated to Art the Science to host the Phase 2 event.

Phase 1 took place on March 19–30 in 2018. During this phase, the artist became an active independent member of the research group on a full-time basis for 2 weeks. He received relevant safety training and was assigned a desk in the research group office space. He participated in all research group meetings and also met regularly with the scientist. The artist was immersed into the research process, from observing experiments to working alongside graduate students. He learned about the different experiments happening in the lab and eventually decided to focus on the research of a specific Ph.D. student for his creative inspiration. He also showcased his artistic practice to the research team by giving a talk and created a preliminary research-based artwork to demonstrate his artistic direction with this project. The artist chose the title *Between the Sand* for his work and completed the first iteration for display in an art gallery after Phase 1.

Phase 2 occurred on February 27th in 2019. It was important to select an art gallery space outside of the academic institution where the scientist conducted his work in order to encourage maximum local community interest and attendance. Art the

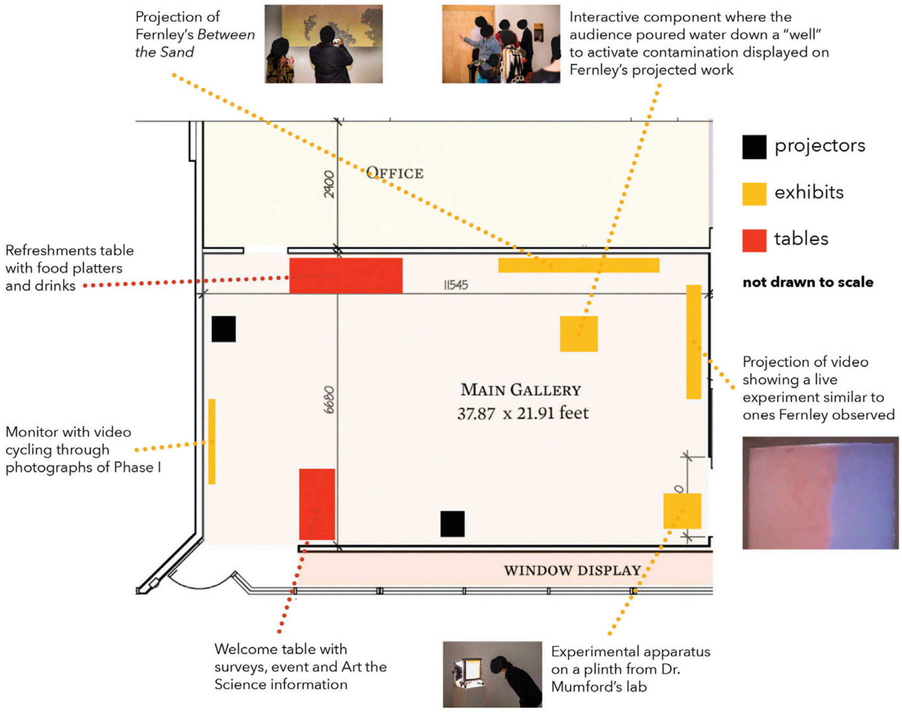

FIGURE 1 | Event set-up at Modern Fuel Artist Run Centre (during exhibition).

FIGURE 2 | Event set-up at Modern Fuel Artist Run Centre (during panel discussion).

Science chose a non-profit artist run centre space called Modern Fuel, located at the Tett Centre, the city of Kingston's hub for creativity and learning.

The event was promoted through various municipal channels including: an article in the local paper, an interview on campus community radio, use of Facebook ads targeting local audiences, and many event listings across various local websites.

The exhibition included projections of both the artist's work and a looping video footage of an experiment, a looping montage of Phase 1 photos displayed on a wall-mounted monitor, and a backlit experimental apparatus displayed on a plinth (**Figure 1**). This setup was altered to accommodate a row of chairs at the front and audience seating for the panel discussion (**Figure 2**).

This Phase 2 version of *Between the Sand* consisted of a wall projection showing digital contamination between sand grains. The contamination would be activated when water was poured down a plastic pipe resembling a well and picked up by a piezo sensor hidden inside. This version of *Between the Sand* had the following artist statement:

"We are all living on the surface of a permeable planet. What goes up must come down, but perhaps more disconcerting, is what goes in.

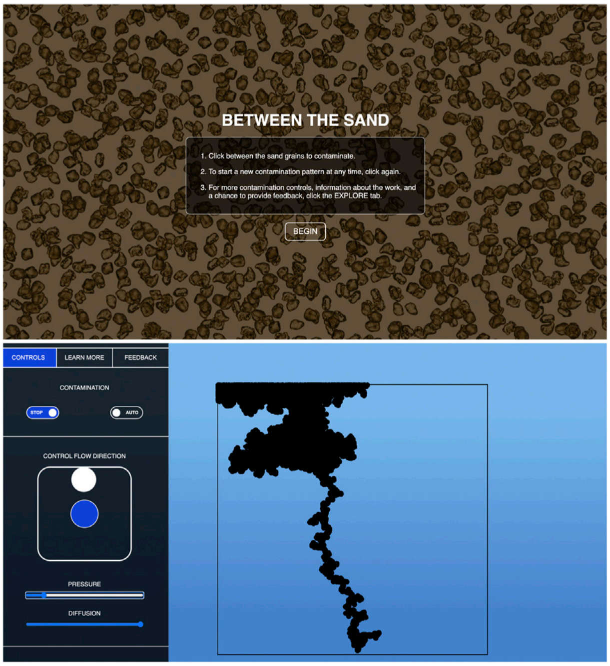

FIGURE 3 | Screenshots of online exhibition Between the Sand.

When chemicals like gasoline, creosote and PCB's are improperly disposed of or spilled, they leach into the ground and contaminate our soil and groundwater, spreading out below us in unseen ways. Pollution does not simply flow through the ground the way it does on the surface. It is under pressure and moves through very small spaces. Understanding this movement can be challenging and leads us to an important series of experiments designed to inform how we might model this movement in the future.

When sand is compressed between two panes of glass, intricate maze-like pathways are formed between each grain. This is the space between the sand. The resulting sections are only 14 grains deep, yet gases, fluids and pollutants move through them in many surprising and beautiful ways. Observing this movement provides scientists and engineers with the data they need to predict and prevent the spread of underground contamination, as well as develop technologies to clean it up.

Between the Sand is an interactive computer program that invites us to explore how our actions affect the ground beneath our feet. It builds a maze of pathways between grains of virtually generated sand. Initiated by the viewer, the maze is "solved" using Invasion Percolation, an algorithm infamous throughout the research group for only following predetermined pathways. In *Between the Sand*, this algorithm is used to present a relationship between direct human action and our unseen subterranean environment. And with that, we can observe the unobservable."

The discussion panel consisted of the artist, the scientist, the Ph.D. student whose work inspired the artist, Art the Science's program evaluation officer and was moderated by Art the Science's executive director. This component helped the audience go behind the scenes of the residency and also learn about the inspiration and the making of *Between the Sand*. A lively discussion with the audience followed the panel.

Phase 3 was launched online on December 5th in 2020. To share this work with audiences around the world, the artist programmed and optimized *Between the Sand* specifically for the web to create an interactive online experience (**Figure 3**). The artist created a digital control panel where visitors can make custom adjustments to the artwork. Some of the options mimic experiments the artist observed in the lab and others are derived from his creative coding experience in making the work (**Figure 3**).

This paper reports on a study that explored the implementation and impact of a novel, three-phase artist residency approach facilitated by a non-profit organization in a scientific research facility. The three phases of the residency are: 1) In the Lab, 2) Local Sci-Art Exhibition Event and 3) Online Interactive Sci-Art Exhibition. This study investigated each phase in order to document and evaluate the impact of the artist residency. The investigation was guided by the following research questions:

Phase 1. What is the value of a science-based artist residency to both the artist and the science research group? How do the artist, scientist, and lab members benefit, or not, from this interdisciplinary experience?

Phase 2. What are the opinions, perceptions and impressions of the attendees at the Local Sci-Art Exhibition Event regarding art and science collaborations and the resulting work of art?

Phase 3. What are the opinions, perceptions and impressions of the virtual attendees at the Online Interactive Sci-Art Exhibition regarding art and science collaborations and the resulting work of art?

METHODS

Phase 1 Evaluation

This evaluation assessed the value of a science-based artist residency to both the artist and the research group, as well as how both the artist and scientist could benefit, or not, from this interdisciplinary experience. In their review of science communication through art, Lesen et al. (2016) recommended using pre/post interviews for evaluating scientist-artist collaborations. Thus, this evaluation of the value of this residency included: 1) pre- and post-residency interviews with the artist and scientist, 2) daily video diary entries from the artist and 3) interviews with lab members following the residency.

Interviews

Both artist and scientist agreed to participate in pre- and post-residency interviews, which would help document their perspectives in both time frames. Due to time constraints and availability, lab members were not asked to participate in an interview prior to the residency. However, they were invited to take part in an interview following the residency. Four lab members agreed to participate. Interviews were semi-structured and took place via Skype video calls for 30–45 min.

See **Supplementary Information SA–SC** for interview questions for the artist, scientist and lab members respectively.

Reflective Concept Map

One component of the pre- and post-residency interviews was a reflective concept mapping exercise that is similar to a brainstorming activity, where an individual writes down relevant ideas pertaining to a topic or prompt. In this case, both artist and scientist were asked to write down ideas that came to mind with the prompt: The value of an artist in a science community. This exercise complemented the interview, as it allowed for an alternative way of reflection and expression of ideas. It provided both artist and scientist time to think freely and to document their ideas on paper instead of responding to questions one after the other.

To provide ample time for participants to develop their reflective concept maps, templates and instructions were sent to the participants prior to the interview. Participants were asked to take about 5 min to jot down ideas and thoughts that came to mind in response to the aforementioned prompt. Concept maps were then sent back to the interviewer and to be later discussed in the interview in more detail. Due to constraints of availability and in an effort to encourage more lab members to participate in a short post-residency interview, the concept map component was not implemented. Instead, an interview question about an arts-based approach to communicate science was asked.

Daily Diary

The artist kept a daily video diary to document the progress and the day-to-day experience during the residency. These entries were made at the end of each day and guided by the following set of questions:

1) What were your goals today?
2) What did you learn?
3) What were you surprised about?
4) What were your challenges?

Data Analysis

Audio for the interviews was recorded and transcribed manually by the interviewer. A thematic analysis was conducted for both interview responses and reflective concept maps (**Tables 1**–**3**).

Phase 2 and 3 Evaluation

To evaluate attendee reception of *Between the Sand* at Modern Fuel, a survey was conducted during the event (**Supplementary Information SD**). Participants were approached by an ATS team member with a clipboard and asked if they wanted to participate. If they agreed, they were asked to review an informed consent form prior to completing the survey. Responses were collected using paper surveys on clipboards and manually entered into a secure online form after the event. This evaluation method was integrated into the event with the host providing context for the survey and encouraging attendees to participate several times throughout the evening. In addition, two ATS members approached attendees with clipboards to make completing the survey as convenient as possible.

A survey (**Supplementary Information SE**) similar to the one used in Phase 2 was conducted online to evaluate *Between the Sand* as a digital exhibition for Phase 3. The survey was linked directly from the work under a tab titled "FEEDBACK" (**Figure 3**) and the results were collected using a secure online form. Participants were recruited by sharing the artwork, mentioning the survey on social media channels, and sharing with relevant networks asking them to proliferate the call for artwork viewing and study participation. Survey responses from Dec 9th to Feb 18th, 2021 were included in this study.

The survey included likert scale questions and open-ended responses. The likert format questions and answers are in **Table 4**.

Phase 2 and 3 Data Analysis

Microsoft Excel (365 for Mac) was used to code, analyze, and visualize the data for both Phase 2 and 3. For the open-ended questions, a thematic analysis was used to capture emerging themes from the participant responses. The number of comments which fell under each theme were documented, along with sample quotes (**Tables 5**, **6**, **7**). Cronbach alpha was calculated for each survey section with three or more statements using the same agreeability scale to determine internal consistency.

RESULTS

Phase 1—In the Lab

Pre-Residency Interviews

The thematic analysis of the Phase 1 pre-residency interview data revealed the common sub-themes (**Table 1**) for both the scientist and the artist under themes of: personal interests, opportunities for engagement, and the value of an artist in the science community.

The pre-residency interviews revealed many common interests between both artist and scientist, despite their different lines of work. The artist used physical algorithms to model real world applications in his visual/audio artwork, while the scientist used computer modelling in his research to better understand where contaminants go in the natural environment. For the artist, the residency was an opportunity to see how he could incorporate a research-informed algorithm in his line of work, whereas the scientist was looking forward to making his research more accessible to the public.

Both the artist and scientist described the limitations in their respective fields to connect and collaborate with people outside their fields for different reasons. The artist spoke about the lack of non-commercial opportunities in the art industry, while the scientist described the challenges to do outreach given their career priorities to advance research in their discipline.

Both the artist and scientist listed "new perspective" as their first thought when considering the value of an artist in the science community. They both described how an artist's insight could inspire others in a scientific environment. The artist related this to a story of how humans in space were able to see a phenomenon that robots would not have been able to identify, showing the importance

TABLE 1 | Pre-residency interview.

Theme: Personal Interests	**Theme:** Opportunities for engagement	**Theme:** Value of artist in science community
Sub-Themes	**Sub-Themes**	**Sub-Themes**
• Science / Technology • Algorithms • Real-world applications • Computer modelling	• Few opportunities and incentives	• New perspective • Inspiration • Knowledge translation • Better problem solving

TABLE 2 | Artist diary.

Daily Question: What were your goals today?	**Daily Question:** What did you learn?	**Daily Question:** What were you surprised about?	**Daily Question:** What were your challenges?
Themes	**Themes**	**Themes**	**Themes**
• Engage with all lab members • Gather context (information on research projects) • Focus on artwork ideas • Create progress pieces to share	• Complexity of different research projects • Amount of control needed in experimental environment • Trial and error with coding	• Importance of safety in the lab • Academic structure is well oiled • Lab members open to playing with experimental set-up • Researchers can take tools they have for granted • First development of artwork	• Time constraints • Identify what research was available • Understanding the research • Find focus of the artwork • Ensure no missed opportunities

TABLE 3 | Post-residency interview.

Theme: Overall experience	**Theme:** Value of artist in science community
Sub-Themes	**Sub-Themes**
• Positive • Many learning opportunities	• New perspective • Improving communication skills • Prompts discussion and engagement

of what a new perspective could bring. On the hand, the scientist voiced how creativity could be enhanced with the presence of an artist and help graduate students think differently about their work, creating a chain reaction of knowledge exchange in and out of the lab.

Interestingly, the concept map reflection allowed the scientist to acknowledge how creative scientists can be, and how much creativity is needed in the world of research. Despite this realization, there was some questioning as to whether or not the scientist's research group would be able to clearly communicate their research to people outside their area of study. In the artist's final reflections of the concept mapping, the artist thought about the possibilities of what society could learn if more cross-disciplinary experiences were implemented in research grants.

For other sub-themes that emerged from both the artist and the scientist, see **Supplementary Information SF**.

Artist Diary

The artist described the first few days as busy and information heavy compared to the rest of the residency. This included undergoing safety training, learning about ongoing research projects, ensuring that he engaged with lab members and preparing a talk about his art practice to the research team. The artist noted the importance of reading through relevant journal articles to have meaningful conversations about the research, despite how challenging this was.

He started to connect with more of the lab experiments than the modelling work but was confronted with the conflict of data accessibility by the end of the first week. The artist described that one of his biggest challenges was figuring out what data he could use, while still providing his own angle. By the beginning of the second week, he shared his intention to focus on the topic of negative space and started learning how complex the modelling was. The artist noted he had more independent study time during the second week, which he used to experiment, and initiate artwork drafts informed by what he learned. Despite spending time on his own work, the artist was still able to encourage lab members to play with their experimental set-ups.

A summary of themes derived from the artist diary can be found in **Table 2**.

Post-Residency Interviews

The thematic analysis of the Phase 1 post-residency interview data revealed common sub-themes (**Table 3**) for both the scientist and the artist under the following themes: overall experience and the value of an artist in the science community.

The residency provided a two-way knowledge exchange, which was positively received by the artist, scientist and lab members. The participants described many learning opportunities which would not have occurred if it were not for this experience. For example, the artist shared his art form, creative coding, with the research lab, which was very different

TABLE 4 | Summary of in-person event survey responses, *n* = 22.

Question	Artist		Scientist		Other
Which of the following best describes you?	7		7		8
Question	**Strongly disagree**	**Somewhat disagree**	**Neutral**	**Somewhat agree**	**Strongly agree**
The interaction between artists and scientists can have societal benefits.	1	—	1	—	21
This event was an effective and engaging way to bring art and science together.	1	—	1	6	15
The panel discussion contributed to my understanding of the artwork (5 responders answered N/A because they didn't attend the panel)	—	—	—	7	10
I learned something new from this artwork	—	—	5	6	11
Question	**Artwork**		**Science Communication Product**		**Both**
Between the Sand is?	4		2		16

TABLE 5 | Themes of open-ended responses from event (only 16/22 chose to respond)[a].

Question: What did you learn from this artwork?

Theme	Number of comments	Comments Examples
Art medium related	4	*"A new perspective on using code as a means of communication"* *"A new form of art"*
Research related	4	*"Learned about how we can have models for percolation/diffusion and that these models are being used to examine bitumen effects in soil."* *"More about the potential for groundwater contamination"*
Value of art and science	4	*"Verified that collaboration between science and art opens new doors"* *"The real world (of science) offers unlimited potential for artistic interaction."*
Value of process	4	*"It made a process visible which makes me look differently at the material"* *"Re-affirmed the process is as important as the product"*

Question: How could this event be improved?

Theme	Number of comments	Comments Examples
More context needed	12	*"More context for the art in the section of the event before the panel discussion. Maybe a large poster like those on the wall at the beginning of a section of a gallery"* *"Information packets/descriptions for people to read about the projects. Provide context and background"*

[a]*Some responses were included in more than one theme, and/or some respondents did not leave comments, therefore therefore total comments will not be equivalent to number of participants.*

from the presentations the students were used to. For some students, it expanded their knowledge about how their research could be visualized and communicated.

Another important theme that emerged from both scientist and lab members was that they found it helpful the artist had some science background, as they believed it made communication and understanding a smoother process. However, the scientist described that while it was helpful for the artist to be able to follow along with the research, it did not necessarily elicit the need for the research group to simplify and therefore improve their communication style. For the artist, the experience in the lab brought many learning opportunities and inspiration for his work, but not without trial and error. The artist's initial ideas for the artwork changed immediately once he got a better understanding of the type of research that was done in the research lab.

For the artist, the greatest challenge was coming up with an angle for his artwork and figuring out what he could contribute. He described how it did not necessarily have to be a ground-breaking contribution, instead, it could be a unique contribution inspired by the ideas and knowledge that were learned during the experience. For the scientist, the logistics and planning of the residency were the hardest part in order to accommodate the artist.

The reflections for concept mapping following the residency were drawn from more concrete examples that both the artist and the scientist experienced. The artist commented on the importance of suggestion while observing experiments. He found that graduate students were quite open to his suggestions and it allowed them to see their experiments in a different light. The scientist saw that having an artist in the lab started to take effect on the ways his graduate students started to

TABLE 6 | Learning themes from online exhibit survey (only 53/55 chose to respond)[a].

Question: What did you take away from this online exhibit?

Theme	Number of comments	Comments Examples
Visual aesthetic/entertaining	14	*"I was mesmerized by the visuals and found the experiment very interesting because it is something I'm unfamiliar with."* *"The beauty that is compressed gas and sand! I was engaged with the colour options and the flow patterns. Very beautiful!"*
Research/science related	*20*	*"Gas/water diffuse differently between different grains of sand, which impacts how watersheds change their landscapes in sandy settings."* *"Experiments using sand can help us better understand how fluids move through porous materials."*
Value/impact of bringing science and art together	20	*"Art can express scientific research in interesting ways and possibly help scientists look at their own work with a fresh perspective."* *"It's really fascinating what happens when someone who isn't the researcher engages with scientific research and presents it through a new perspective. I think for a lot of science communication that distance from the research is important to effectively share the work with new audiences, and Between the Sand is a great example of this."*
Uncertainty	4	*"I'm not sure what I was supposed to take away from the exhibit, but it was pleasant to watch."* *"It is fun but I'm still left wondering more about the purpose of this research."*

[a]*Some responses were included in more than one theme, and/or some respondents did not leave comments, therefore total comments will not be equivalent to number of participants.*

TABLE 7 | Areas of improvement from online exhibit survey (only 50/55 chose to respond).

Question: Is there anything that would have made this online experience better?

Theme	Number of comments	Comments Examples
Providing more context	14	*"Maybe more context about why this is important or how it's related to natural environments"* *"The "learn more" section is very detailed and informative, but it might benefit from some kind of concluding section that helps the user understand what it all means practically"*
Technical components (User experience)	24	*"An option to change the size of the sand grains would have been nice—smaller grains would make the diffusion patterns more delicate"* *"Maybe some audio component? Sole aspect that speeds up or slows down as the fluid reaches new cavities or barriers"*
Questions/Needed clarification	4	*"Could different coloured contaminations mean different things. could the contamination linger longer (and not leave) and what would that mean?"* *"I wonder why scientists are studying this? Why do they need to predict how gases will travel through porous media?"*

approach their research communication, such as the importance of a balanced colour palette when creating a data visualization. In addition, the scientist shared that his sentiments about the value of an artist in the lab pre-residency remained the same post-residency, including the increase of communication, accessibility, and knowledge sharing.

For other themes that emerged from the interviews, **Supplementary Information SG**.

Phase 2—Local Event

An estimated 35 people attended the local event. Twenty-seven individuals were present during the art exhibition panel session not including ATS team members or panelists. Integrating the survey into the event seemed to increase the survey response rate, which resulted in 22 completed surveys. Cronbach's alpha for three statements using the same likert scale were calculated to be 0.53.

Attendee backgrounds included seven artists, seven scientists and eight individuals that had a different background or a combination of the two. Ninety-five percent (21/22) of the attendees strongly agreed that the interaction between artists and scientists can have societal benefits. In addition, 95% (21/22) agreed that this local event was an effective way to bring art and science together. Seventy percent (17/22) learned something new from the artwork. When asked to decide whether *Between the Sand* was an artwork or a science communication product, 73% (16/22) of the participants responded that it was both (**Table 4**). In addition, participants responded that artist residencies in science labs are important because: they provide inspiration and new ideas to the scientist and artist (20/22), the artist provides the scientist with a new perspective on their research

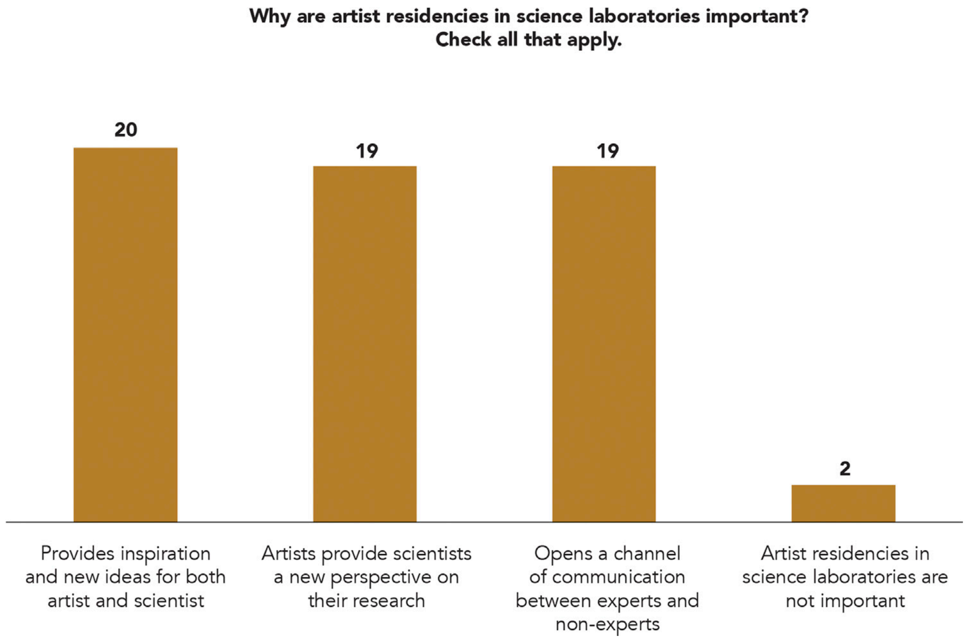

FIGURE 4 | Distribution of responses to why artist residencies in science laboratories are important. Participants were allowed to select more than one answer, *n* = 22.

(19/22), and it opens a channel of communication between the expert and non-expert (19/22) (**Figure 4**).

According to participant responses, art grants (20/22), science grants (18/22) and universities (15/22) should be the main funders of artist residencies in science labs (**Figure 5**).

Answers to open ended questions were provided by 16 participants. Four themes emerged in response to "What did you learn from this artwork?". The first was about the artwork medium where four participants commented on *Between the Sand* using a new artistic medium—creative coding. The second theme related to research where four participants commented on learning about the science undertaken by the research group. Another theme explored the value of art and science together with four participants expressing a positive association when science and art are combined. Finally, the theme of valuing the process also emerged with four participants noting that they valued learning about the process behind the research methods (**Table 5**).

Requests for feedback on improving the event revealed that (according to 12 participants) more context was needed to frame the residency program and artworks on display (**Table 5**). Suggestions included more informative signage at the entrance and perhaps a handout/program would have helped with providing more context. Two participants mentioned that more gallery space would have improved the event.

Phase 3—Online Exhibition

A total of 55 responses were submitted between Dec 9th and Feb 18th, 2021. Most of the participants were artists (14/55) and scientists (17/55) with 24 individuals identifying a different background than the aforementioned. Participant age ranges fell into four categories: 20–29 (17/55), 30–39 (22/55), 40–49 (11/55), and Over 50 (5/55). Cronbach's alpha for five statements using the same likert scale were calculated to be 0.77.

Survey responses revealed that 83.6% of the participants enjoyed the online exhibit (29 somewhat agreed, 17 strongly agreed, *n* = 55) and, 61.8% learned something new from the exhibit (16 somewhat agreed, 16 strongly agreed, *n* = 55). The majority (85.5%) of participants agreed that the online exhibition was an effective and engaging way of bringing art and science together (27 somewhat agreed, 20 strongly agreed, *n* = 55), 70.9% of participants would recommend the exhibit to a friend (18 somewhat agreed, 21 strongly agreed, *n* = 55) and only one participant had technical difficulties during their online experience of *Between the Sand* (**Table 8**).

Survey repsonses indicated that 81.8% of participants thought that *Between the Sand* was both an artwork and a science communication product (45/55). According to participant responses, science grants (49/55), art grants (46/55), and universities (43/55) should be the main funders of artist residencies in science labs (**Figure 6**).

A total of 53 participants (out of 55) provided comments on what they learned from the online exhibit. Most participants commented that they learned more about the research and/or the impact of bringing art and science together. Twenty comments were placed under the research/science related theme, which took into account concepts such as algorithms, gas diffusion, and contamination. Twenty comments were also included under the theme of the impact of bringing art and science together, which mainly included comments around how art and science can provide new perspectives and knowledge accessibility to the

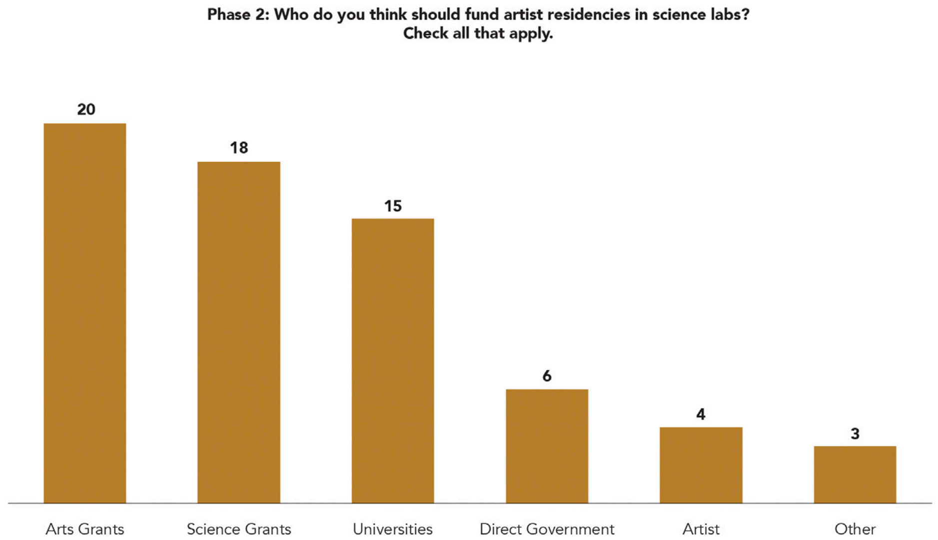

FIGURE 5 | Distribution of responses to who should fund artist residencies in science labs. Participants were allowed to select more than one answer, $n = 22$.

TABLE 8 | Summary of survey responses, $n = 55$.

Question	Artist	Scientist			Other
Which of the following best describes you?	14	17			24
Question	**20–29**	**30–39**		**40–49**	**Over 50**
What is your age range?	17	22		11	5
Question	**Strongly Disagree**	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Strongly Agree**
I enjoyed this online exhibit	—	—	9	29	17
I learned something new from this online exhibit	1	4	16	16	18
This was an effective and engaging way of bringing together art and science	—	3	5	27	20
I would recommend this online exhibit to a friend	1	5	10	18	21
I had technical difficulties during my online exhibit experience	37	15	2	1	—
Question	**Artwork**	**Science Communication Product**		**Both**	**Other**
Between the Sand is?	2	5		45	3

public. Fourteen comments were strictly about the visual aesthetic or entertaining interaction with the online exhibition, while only four comments shared sentiments of uncertainty about the purpose of the exhibit. See **Table 6** for examples of responses for each theme.

A total of 50 participants (out of 55) provided comments on what could have improved their online experience. Most comments (24) fell under the theme of technical components which could improve the overall user experience, such as changing specific controls, including audio or additional features. Fourteen comments centered around providing more context and/or a bigger picture as to why this was important research and how it could be applied. Finally, four comments were placed into the theme of questions and/or uncertainty of the purpose of the artwork. See **Table 7** for examples of responses for each theme.

DISCUSSION

Phase 1—Impact and Perceptions

Artist Perspective

For the artist, there was a newfound appreciation for the structure of research from the planning and precision of experiments, to the

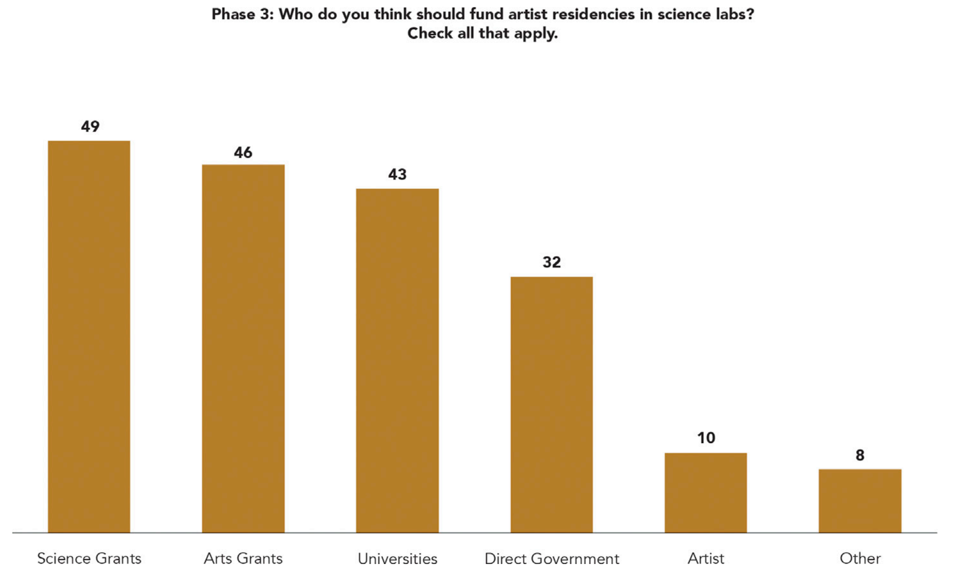

FIGURE 6 | Distribution of responses to who should fund artist residencies in science labs. Participants were allowed to select more than one answer, $n = 55$.

sheer knowledge and dedication of the research group. This realization motivated the artist to do more readings, to better understand the technical terms, and make more informed questions in order to find his own angle for the artwork. The short time frame of the residency also encouraged the artist to step out of their comfort zone to seize opportunities and ask questions. Similar sentiments were also reported by artists who participated in the Wellcome Trust's Sciart Programme. Initially, they felt intimidated or in awe of stepping into the realms of science, but then gradually gained confidence to affirm their identity in an unfamiliar domain (Glinkowski and Bamford, 2019).

In the pre-residency concept mapping, the artist identified the importance of new perspective, and how an artist could potentially contribute to scientific research. This theme seemed to influence the artist's approach early on in the residency, when he was trying to find what his contribution would be. The artist was certainly not alone in this thinking, as the notion of whether art can link to improvements in scientific process and outcomes has also been questioned by others (Stevens et al., 2019). There have been moments when this has occurred, for example, when a phenomenon in Antarctica photographed by Schulthess (1960) prompted further scientific analysis (Tricker, 1972). However, this may not always occur, and artists may find themselves redefining what that contribution means to them. During this residency, the artist quickly realized that his contribution would not be a "eureka" moment for the research group, but rather his own unique contribution based on what he experienced.

Scientist and Research Group Perspective

The scientist and his research group certainly saw and experienced the impacts of having the artist in the lab. Similar to the artist, the theme of new perspective was mentioned in the scientist's pre-residency concept map and was manifested during the residency in many forms. Lab members described how their repetitive tasks suddenly had new meaning, as they thought about how to explain what they were doing and why. With encouragement from the artist, graduate students broke away from the scientific methodology they knew, to play and look at their experiment in a different way. Such sentiments around new perspectives were also reported by scientists who participated in the Sciart Programme (Glinkowski and Bamford, 2019).

While the scientist shared his enthusiasm about the impact of the artist on his research group, his skepticism in his own ability to communicate still remained post-residency. The scientist credited the artist for keeping up with the technical jargon he used but questioned whether he could actually communicate his work to someone without the artist's science background. Interestingly, Glinkowski and Bamford (2019) reported that 66% of artists who participated in the Sciart Programme had some kind of scientific background prior to the project. Thus, it is possible that artists with a closely aligned background could increase the chances of successful interdisciplinary experiences or collaborations. Otherwise, facilitation and a longer residency period should be considered to ensure an effective artist and scientist interaction.

Despite mostly positive comments, one graduate student voiced the uncertainty of whether this science-art approach would be widely accepted by the scientific community, particularly experts in his field who were older and more traditional. Previous attempts to gauge the role of art in science communication among scientists have shown that while 55% agreed that science-inspired art made them reflect on alternative ways of communicating science, a majority (72%) would not consider or were not certain about using art in conjunction with their scientific work (Curtis et al., 2012). One reason that could explain the hesitation to integrate the arts may go back to the nature of the scientific profession. As the scientist mentioned in his pre-residency interview, for young researchers, the focus is on advancing their research discipline which will in turn advance their career. This notion and the lack of incentives to do outreach among scientists is also noted by Schnugg (2019) and Glinkowski and Bamford (2019). Perhaps this observation is a good prompt to question and/or challenge the current structures in place, so that there is more support and opportunities for scientists to work with those outside their disciplines.

Value of Interaction

Despite the 2-week duration of this residency, it still allowed for many learning opportunities and valuable insights for the artist, scientist and research group. Themes such as new perspectives and benefits to society overlapped in the concept maps for both the scientist and the artist, pre- and post-residency. This consistency suggests that these particular ideas and expectations continue to be important components of the "value of an artist in the science community", perhaps because they were observed during the residency. It may also suggest that shared values and respect for the other discipline are integral for a meaningful and successful residency experience.

While there were many themes which were shared between the artist, scientist and lab members, there were also some which were only identified by one or the other. For instance, the artist likely emphasized the importance of asking questions and validating work since this was something he was actively doing in order to achieve his goal of creating an artwork that accurately reflected the research being conducted. On the other hand, the scientist and lab members highlighted the importance of gaining new skills from the artist, as this could be helpful in their research careers. Observing more conversations and discussions was also likely easier for the scientist to notice as this was an expectation he had before the residency. Since both parties had different priorities and expectations to begin with, it is likely that some benefits and observations would also be different.

Overall, the residency left the artist feeling confident and excited to pursue the next step in his challenge to create and present the research-inspired artwork. It also provided him with a learning experience which could inform his future collaborations and art practice. For the scientist, he anticipated that these new ideas and perspectives gained from the residency would percolate through conversations beyond their immediate peer group, and eventually to the public sphere. He also highly recommended other researchers to take on such an opportunity, as the benefits for the research group were well worth it.

Residency Model

Artist residencies may range from 1 week to 1 year in duration and function differently. The structure of this residency did not require the artist to have a finished art piece at the end of the 2 weeks. Rather, the 2-week time frame provided space for learning and ideation to inform the artwork. The artist was then provided several months to complete the artwork on their own with some correspondence with the research team if needed.

It is important to note that the structure of this residency was not an artist-scientist collaboration where the two worked together to create a piece, as seen in the Sciart Programme (Glinkowski and Bamford, 2019), SciArt Center Bridge Residency or in Halpern's (2011) work on observing the collaborative process between artist and scientist. Instead, the artist was integrated into the scientific environment as a fellow lab member, to draw inspiration and knowledge for his artwork.

Interestingly, Glinkowski and Bamford (2019) evaluation interviews revealed that the Sciart Programme seemed to favour the artists, in that they had the most to benefit from the opportunity. Given the nature of a scientist's profession, it may be understandable why they were not as heavily involved. However, ATS's residency approach may help to overcome some of these barriers by providing flexibility of involvement for the scientist as to not take away time from their research. In addition, the artist is given an opportunity to explore and develop relationships with other lab members, which could have a larger, collective impact compared to a one-on-one collaboration.

Phases 2 and 3—Local/Online Events

Exhibition Logistics and Evaluation

Since the in-person event was held in a community environment (not at the university), it allowed for a broader audience reach, outside the university establishment. On the other hand, the online exhibition provided a larger and more accessible public platform for the artwork. Since it was optimized for most web browsers and rural internet connections, most participants (94.5%) did not report any technical issues with the exhibition interaction. Internet and browser accessibility verification is an important consideration when creating online exhibition experiences.

Similar to other science-art outreach initiatives (Drumm et al., 2015; Rosin et al., 2019), the *Between the Sand* local event embedded evaluation into the program to encourage participation and to ensure that participants understood the context of the questions they were asked. Throughout the event, participants were reminded to take part in the survey and volunteers circulated the room to provide survey materials, making it easily accessible. Similarly, for the online exhibition, the survey was incorporated into the menu and participants were able to access this link directly in contrast to the customary feedback popups that were triggered upon leaving the webpage.

Attendee Demographics

The local event had attendees from varying backgrounds with artists and scientists comprising a majority. This suggests that integration of art and science is of interest to both groups. This was also observed across participants viewing the work online. The age range of participants for the online exhibition revealed that age groups (20–39 years of age) who are generally more comfortable with technology made up the majority of participants, while only a small portion (9%) were over the age of fifty. This lower senior participation rate may be attributed to lack of access to technology or skills to access online experiences. A general lack of seniors online may also have contributed to this lowered participation as the online exhibition was shared digitally via social media. Finally, senior populations may be less interested in digital art forms compared to traditional ones (Drumm et al., 2015).

Learning Opportunities

Art provides an avenue of learning similar to the museum and science centre experiences. Although *Between the Sand* cannot compare to a full museum or science centre experience, both the in-person event and online exhibition provided an opportunity for free-choice learning that is guided by the learner's needs and interests (Dierking and Falk, 2003).

The local event fostered some elements of a discovery learning environment (Hein, 1998) which had a range of active learning modes, including: 1) The interactive artwork that attendees could physically manipulate; 2) Videos and actual apparatuses from the lab; 3) A panel discussion with a Q&A and 4) Opportunities to connect and discuss with the artist, scientist, and lab members directly about their work. As a result, over three-quarters (77.3%) of the participants agreed they learned something new from the artwork and provided a wide range of answers of what they learned from the experience. These responses stemmed from learning about a novel art medium (creative coding) to learning about specific details from the scientific research and process. For many, attending this local event affirmed the value of bringing science and art together. In addition, participants who watched the panel discussion agreed that it contributed to the understanding of the work. This suggests that incorporating artist/scientist talks along with the artwork can enrich the public learning experience.

However, this local event did miss some components of a discovery learning setting, which many participants actually noted in their feedback. The event lacked didactic components such as labels, panels or handouts that provided further context, prompts or questions to encourage the visitors to find out more about the topic (Hein, 1998). Including more didactic components would have also allowed participants to get a quicker understanding of the topic upon entry and help provide context during the time they were waiting to interact with the artwork, lab equipment, artist, scientist or lab members.

The online exhibition fostered more elements of constructivist learning, as there was no "right" way to experience the exhibition, allowing for experimentation and play (Hein, 1998). Users were able to click in multiple areas and adjust different settings to see how they could change the flow pattern of contamination. However, there were didactic components in the menu which provided more context about the artwork and scientific research. While this digital version certainly did not have the same in-person learning opportunities as the local event, it did provide more accessibility (anybody with the link could interact with the exhibition) as well as time to play and explore (unlike the local event which had a clear start and end time).

For the online exhibition, 61.8% of survey participants agreed that they learned something new. Similar to the local event, participants provided a range of responses on what they learned. Some were fixated on the aesthetic components of the exhibition, others learned about the importance of the research which the artwork was inspired by, and many were intrigued by this cross-disciplinary approach to engaging the public. There were also a few participants who were left with more questions and wanted to learn more about the artwork or research. Such diverse responses are almost expected from constructivist learning, since providing the participant an opportunity to construct personal knowledge means there is a possibility for them to have a different interpretation from what the designers (or in this case, the artist) intended (Hein, 1998).

Interestingly, the feedback for the online exhibition would strengthen this constructivist learning experience. Many participants suggested more modes of learning through added features that would allow for even more play and experimentation, such as changing the size of the sand grains or incorporating audio. Others wanted different ways to connect to the research and how this could be applied in the real world. All in all, participants enjoyed this approach to learning, which provides promising prospects for future digital learning experiences integrating art and science.

Science-Art Perceptions

Communication to promote both local and online exhibitions positioned *Between the Sand* as a research-inspired artwork, yet the majority of participants (79.2%) from both exhibitions identified it as both an artwork and a science communication product. This finding suggests that science-based art may have the potential to communicate science, even when it is not promoted as a science communication effort.

Most participants (88.3%) of both the local and online exhibitions thought the initiatives were an effective and engaging way to bring art and science together. Both scientists and artists comprised the participant group which reveals that both groups may be interested in interdisciplinary projects combining art and science. Furthermore, 95.5% of survey participants from the local event strongly agreed that interaction between artists and scientists can have societal benefits. This finding supports the recent trend in increased initiatives centred around art and science collaborations (Feder, 2021; Gewin, 2021). It should be noted however, that some artists are hesitant about having their art serve as a science communication product (Sleigh and Craske, 2017).

Artist Residencies in Science Labs

Survey participants at the local event were asked why they thought artist residencies in science labs were important and were given four possible answers (**Figure 4**). Most participants thought that artist residencies in science labs can be beneficial to both the participating artist and scientist by providing inspiration and new ideas. This result aligns with the findings for Phase 1, where the sub-themes of new perspective and inspiration emerged for both artist and scientist before the residency (**Table 1**). Similarly, a survey by Sleigh and Craske (2017) revealed that artists collaborating with scientists allowed for the development of valuable relationships and enriched their art practice. Participants also acknowledged that these residencies are important, because the artist can provide a new perspective on scientific research. New ideas are critical for advancing scientific discovery, thus inviting a new perspective into the research group may help unveil pathways to advance and/or communicate the research. The Phase 1 findings also support this notion, as the artist, scientist, and lab members shared this view after the residency (**Table 3**).

Survey participants of both local and online exhibitions were asked to select all listed entities that should fund artist residencies in science labs. Science grants (67/77 responses) and arts grants (66/77 responses) were the most selected funders followed by universities (58/77 responses) and direct government funding (38/77 responses). These responses reveal that public perception of funding is not skewed to either discipline and instead seems to call upon both

TABLE 9 | Summary of recommendations for future residencies.

Art the science residency recommendations	
Funding	Should cover the following costs: • Artist's living costs • Artist fee • Scientific materials • Artwork production materials • Exhibition support
Scientist experience	• Departmental encouragement and support • Engaged research group • Involvement in artist selection process • Facilitation by residency provider
Artist experience	• Adequate residency duration • Full-time basis • Integration into the research group as a valued member • All training required for lab autonomy • Creative control over artwork direction • Equal access to reagents and equipment when possible • Facilitation to support the artist and scientist when required
Public exhibition	Local: • Host exhibition events outside of research institutions • Invest time into directed exhibition promotion initiatives to engage diverse audiences in the local community Online: • Include UI/UX considerations during the design process • Create inclusive online experiences
Evaluation	• Design and plan program evaluation initiatives well ahead of the residency and inform hosting research facility and artist • Embed evaluation initiatives as part of the event experience not as an afterthought

science and arts grants to fund such interdisciplinary initiatives. In Europe, government grants already support science-art projects (e.g., STARTS initiative), while other countries like Canada (where this residency took place) are currently lacking formal science-art funding opportunities. Survey responses also revealed that universities could be appropriate funders for artist residencies in science labs. This funding would likely come from grants that principal investigators typically apply for. However, while there are benefits of incorporating budgets for science-art initiatives in scientific grant applications, the artist's experience may become outcome-driven and constrained to meet the expectations of the research objectives (Sleigh and Craske, 2017).

Recommendations

Recommendations from the findings of this paper as they relate to facilitating a comprehensive science-art residency program are documented in **Table 9**.

Establishing funding for artist residencies in science labs is critical for artists and scientists interested in collaborations. While traditional models for artist residency funding are already established, cost for scientific equipment and supplies need to be considered when budgeting for a science-artist residency. In addition, the scientist should seek support from their department in order to engage a broader research community with the artist in residence. Organizations providing the residency should ensure the scientist is part of the artist selection process early on, when potential themes and other residency application criteria are established. Creating such criteria with the scientist will help outline the expected outcomes and vision for the residency. It is important to establish the incoming artist as a member of the research group to ensure a truly immersive residency experience. In addition, all parties involved should acknowledge that science communication may not be one of the artist's goals during the residency. The artist may consider creative input from the scientist, but should retain the ultimate creative control for the direction of their work.

Defining an adequate residency duration for Phase 1 of an immersive residency is critical for the success of the other two phases. The most feasible recommendation would include a 2–3 weeks immersive component with compensated self directed time for the artist to complete their artwork for the subsequent exhibitions. As the artist noted in their post-residency interview, 2 weeks would not have been enough time to complete the artwork and therefore, a longer duration would be ideal if the artist is expected to have a finished art piece at the end of the residency. On the other hand, the scientist fully supported the 2-week duration of the residency, with a possibility of extending another week only to accommodate unforeseen circumstances (e.g., no lab experiments being conducted).

Lengthening or increasing the frequency of events in the future could contribute to an increase of attendees. However, the time of both the artist, scientist/research team should be accounted for in the planning of the events to ensure it is feasible. Otherwise, evaluators must be adaptable and consider alternative methods of engagement and data collection (e.g., digital/online events). It may also be helpful to connect with the artists and scientists after Phase 2 or Phase 3 of the residency to collect their thoughts about final artwork and their experience with public engagement.

Limitations

Due to the small sample size and the nature of this science-art residency, these findings may not apply to broader science-art experiences or collaborations. Respondents from the Phase 2 survey were limited to the small city of Kingston, Ontario within a short timeframe (1 day, 3 h event during inclement weather), which likely contributed to the small number of attendees.

In addition, surveys were not conducted before the in-person or online exhibition, as these questions may have discouraged attendees and/or affected their perceptions before experiencing the actual event and therefore, impact their final impressions. Although the Chronbach's alpha for the Phase 2 survey was low, it should be noted that only three statements were included in this test, along with a smaller sample due to inclusion of a statement with non-applicable (null) as one of the answers. A reduced alpha is commonly seen in tests where there are fewer items (Nunnally and Bernstein, 1994).

While it would have been interesting for the scientist and/or research team members to document their experience in a daily diary, this was not practical given their busy schedules and the immense effort that was already put into the logistics of having an artist in their laboratory in the first place. Unlike other science-art residencies and programs (e.g., Wellcome Trust Sciart Programme) where scientists and artists are both responsible for creating the artwork, this residency immerses the artist into a scientific research environment, allowing them to learn and collect information for their research-inspired artwork. This approach also allows the research team to engage with the artist without compromising their research priorities. While more documentation is ideal, it is important to draw boundaries and understand when evaluation can impede the experience for participants.

CONCLUSION

Through the use of qualitative and quantitative methods, including interviews, concept mapping, video diaries, and surveys, these findings revealed that a comprehensive Science-Artist Residency program facilitated by Art the Science had a valuable impact on everyone involved: the artist, the research group, and the public. Providing opportunities where disciplines can work together also enables a creative means to connect with the general public through story and process to ignite meaningful discussion, knowledge sharing, and active learning.

AUTHOR'S NOTE

The scientist and artist were introduced by their real names because *Between the Sand* is a public artwork which includes complete documentation of the residency and those involved online as well as articles published in media outlets. Because of the public nature of the residency, it is not possible to guarantee anonymity to the scientist and artist. They were both made aware of this from the beginning and did not object.

DATA AVAILABILITY STATEMENT

Data supporting the conclusion of this article will be made available by the authors upon request in accordance with the Research Ethics Board of Laurentian University's Research Office.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Board, Laurentian University Research Office. The participants provided their written informed consent to participate in this study.

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JK—writing, editing, data collection, data analysis, data visualization CL—writing, editing, data collection, data analysis, references CB—editing, ethics.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.690489/full#supplementary-material

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Intensive, Short-Term Presenting With a Science Outreach Program Enhances Positive Science Attitudes and Interest in Lifelong Learning About Science

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This study investigated impacts of intensive, short-term participation as a science outreach presenter on attitudes towards science and interest in lifelong learning about science. Participants included high school and university students who volunteered to assist as presenters over 1 week when Science Caravan—an extensive science outreach program in Thailand, run by the National Science Museum—visited their locality. This study employed mixed methods over two phases. Phase One involved three questionnaires. Two questionnaires were administered to current presenters (N = 690), pre-presenting (before training) and immediately post-presenting at 12 locations of the Science Caravan tour in 2017–2018. A third questionnaire collected data from previous, alumni presenters (n = 726). Phase Two involved interviews with current presenters (n = 19) and alumni presenters (n = 19). While presenters already had positive attitudes towards science, the brief but intensive experience of being a Science Caravan presenter enhanced science attitudes in four scales—with more positive attitudes about Self-concept in science, Value of science to society, and Future participation in science, and decreased Anxiety about science presenting. Participation had a greater impact of reducing anxiety in female presenters compared to male presenters. The experience of presenting with Science Caravan led to the development of more positive attitudes towards science and increased interest in lifelong learning activities regarding science, including presenters' interest in science-related education. The increased interest in lifelong learning activities was correlated with positive attitudes about and self-efficacy in science. This study provides evidence that a short-term, intensive experience of science outreach can lead to increases in positive attitudes towards science and lifelong learning.

Keywords: science outreach, presenter, lifelong learning about science, attitudes towards science, science presenting

INTRODUCTION

The utilization of scientific knowledge and technology facilitates life in the workplace, offers healthier and longer lives, and provides more convenient lifestyles (Triyarat, 2017). Understanding scientific knowledge and engaging with science can improve science literacy. Kawamoto et al. (2013) suggested that improving scientific literacy in modern society is relevant for determining scientific policies that support national development. Negative attitudes about studying science are of concern to governments around the world (Venville et al., 2013), and research has endeavored to find ways to increase students' positive attitudes towards science (Kind et al., 2007). It is important to increase interest in lifelong learning in science (Cobern, 2015). The development of effective science education is a notable strategy used to promote scientific literacy (Chalamwong and Pomlakthong, 2004).

Lifelong learning is defined as "all learning activities … undertaken throughout life, with the aim of improving knowledge, skills, and competence within a personal, civic, social, and/or employment-related perspective" (European Commission, 2001, p. 9). According to Tuijnman and Boström's (2002) review, lifelong learning has several features, which may be different from other education approaches: (1) such learning is based on learners' needs; (2) self-directed learning is central to individual learning throughout life; and (3) such learning can take place in a variety of settings. In this sense, lifelong learning is not confined to structured, institutional settings such as schools, libraries, museums, science centers, and zoos, but can include daily experiences at home, at play, from travel, reading magazines, surfing the internet, watching television, etc. (Longnecker, 2016). Therefore, many efforts towards bridging the gap of an individual's learning between formal and informal contexts reflect an awareness of lifelong learning approaches in society (Rajala et al., 2016). For example, Jones et al.'s (2017) study found that experiences derived from engaging in science-related hobbies, events, and leisure activities, which mostly began in childhood, influenced people's lifelong science learning interest.

From the perspective of learners, encountering science information in a wide range of contexts outside school settings—both structured and unstructured—can influence attitudes and abilities (Lin and Schunn, 2016). In the context of both structured and free-choice learning environments, Longnecker (2016) noted that an individual's engagement with and use of new information is influenced by the individual's identity, a construct that comprises values, beliefs, attitudes, prior understanding, and skills. This model is consistent with findings of Kouthouris and Spontis (2005) who asked 329 university students in the United States about their intention to participate in outdoor activities. Their results indicated that students' intentions to participate in the activities were significantly predicted by perceived behavioral control, role identity, and attitudes toward participation. Engaging in learning environments where learners are self-directed and intrinsically motivated to discover and explore for themselves can improve their perceived value of particular, domain-specific knowledge (Kong et al., 2014). Moreover, participating in science-based activities can influence students' attitudes towards science. Gibson and Chase (2002) showed a longitudinal impact of an inquiry-based, hands-on science program, when attitudes towards science became more positive. These findings align with those of studies where there have been positive impacts on students' interest in science and thus an eagerness to learn science by using science-based activities (Laursen et al., 2007).

It is apparent that many factors influence science attitudes, and these attitudes in turn affect science learning. Previous research has found strong links between contributing to science outreach and positive attitudes towards science (Larsen, 1994; Toolin, 2003). This study fills a gap related to short-term science outreach programs, that participation as volunteers might encourage positive attitudes towards science, which could in turn contribute to lifelong science learning behaviors. Analyses of attitudes towards science from such programs will help predict whether and how students will engage with science later in life and in their careers. Furthermore, improving understanding of how factors influence attitudes towards science can enable teachers, counsellors, and outreach organizers to enhance student achievement.

Focus of This Study

This study focuses on a short-term science outreach program—the Science Caravan, an initiative run by the National Science Museum (NSM), Thailand—and is guided by these research questions:

1) Does presenting in a short-term outreach program change presenters' attitudes towards science? If so, how?
2) Does presenting in a short-term outreach program influence lifelong learning interest and behavior of volunteer outreach presenters?

Theoretical Framework

This study was informed by the Theory of Planned Behavior and self-efficacy. Both constructs are described below.

The Theory of Planned Behavior

The Theory of Planned Behavior (Ajzen, 1991) is used for predicting behavior in many various contexts (Ajzen and Driver, 1992). The Theory of Planned Behavior states that an individual's intention can predict the possibility of engaging in action, and that this intention is influenced by attitude towards the behavior, subjective norm, and perceived behavioral control. In other words, individuals have beliefs regarding their ability, knowledge, and skills to perform the behavior, beliefs about what others think, and beliefs about whether they have sufficient resources and opportunity. According to the Theory of Planned Behavior, the more favorable the attitude and subjective norm concerning a behavior, and the higher the perceived behavioral control, the more likely a person will be to perform the behavior (Ajzen, 1985). However, internal and external factors can interfere with performing intended behavior (Ajzen, 1985). For example, to carry out the behavior of visiting a

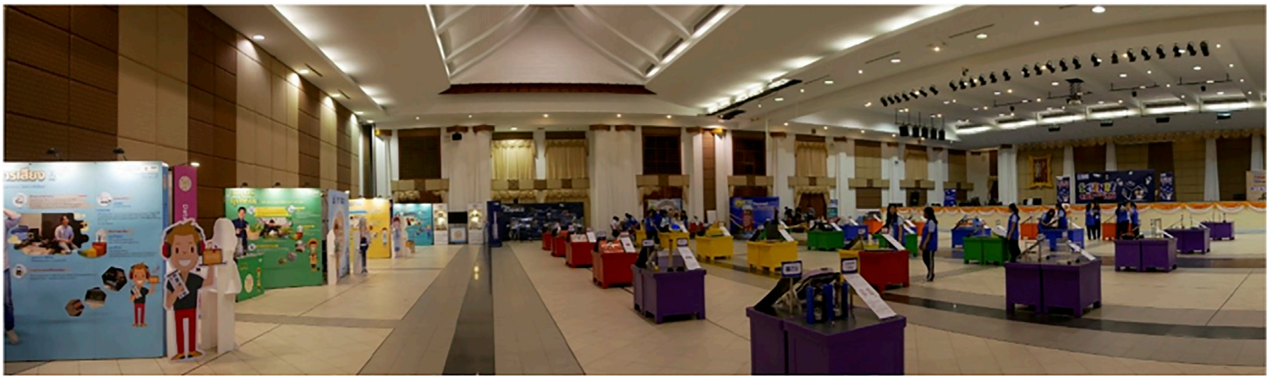

FIGURE 1 | A typical setting of the exhibition space of Science Caravan being prepared for opening to visitors.

science museum on weekends, learners may require not only positive attitudes towards science and self-efficacy in science but also resources (time and money). One important external factor is support (Longnecker, 2016); in the example of visiting a science museum, children in particular would need family support and transport.

Self-Efficacy

Self-efficacy is described as "people's judgments of their capabilities to organise and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 94). Bandura (1986) found that individuals with the same level of ability can master the same task at different levels of performance. Individuals with higher self-efficacy are more likely to have higher performance than those with lower self-efficacy (Frey, 2018). In different contexts, an individual can perform at a different level of achievement if that individual perceives a different level of self-efficacy. As such, learners are more likely to carry out a behavior if they have a high level of self-efficacy. Self-efficacy also influences outcome expectations; individuals who judge themselves with higher efficacy will expect more positive performance outcomes (Bandura, 1986). For example, a student who is confident in their ability in science may anticipate positive achievements (Lent et al., 2008).

METHODS

The case study context is described before detailing the research methods, including the participants, data collection methods, and analyses.

Case Study Context: NSM Science Caravan

This study focused on Science Caravan, an outreach program of the NSM Thailand. To serve Thai youth across the country, Science Caravan was initiated in 2006 to promote public awareness of science and technology and inspiration about science in Thai students in rural and regional communities. Another aim is to encourage skills development regarding creativity, critical thinking, problem-solving, and science process skills. Science Caravan is a large-scale science outreach program, bringing 60–80 science exhibits (**Figure 1**), and hands-on activities, science shows, two science labs, a mobile planetarium, and professional teacher training to communities in at least 20 Thai provinces each year. Over more than 10 years, about 8,000 volunteer presenters have facilitated and encouraged approximately 1,000,000 visitors to be actively involved in science activities.

The Science Caravan has developed a program for volunteer presenters and works with local communities to offer an opportunity at each venue for 60–70 local high school or undergraduate students who assist Science Caravan as presenters. Since basic science knowledge is a requirement for presenters, most presenters are recruited from undergraduate students studying science majors or high school students studying in the science stream.

A Science Caravan trip starts on a Saturday morning, with transportation to the target location. On Sundays and Mondays, while Science Caravan is being set up, 60–70 local presenters receive 2 days of training from NSM staff in essential science communication, natural science, and critical thinking in relation to solving common problems that arise at Science Caravan. During the science communication training, presenters develop their skills and are explicitly told of their value to the Science Caravan program by inspiring visitors about science. After receiving training, each presenter is assigned to a specific exhibit or activity, which they are responsible for from 8.00 a.m. to 4.30 p.m., Tuesday to Friday; they receive mentorship by NSM staff. After finishing the activities each day, presenters are given feedback about their performance and told about plans for the next day. After 4.30 p.m. on Friday afternoon, there is a debrief for presenters while Science Caravan is disassembled in preparation for moving to the next location.

This paper reports one part of results from a research project examining the impact of intensive contribution as a presenter in a short-term (6-day) program in an informal science learning environment (Sripaoraya, 2020). For this paper, a case study approach with mixed methods was adopted and comprised two phases. Phase One used a convergent parallel design to examine both research questions. Data were gathered using questionnaires administered to current and alumni presenters. Phase Two involved in-depth interviews investigating how contributing as a presenter influenced attitudes towards science and lifelong learning behavior. Phase Two used explanatory sequential design (Guest, 2013), in which the quantitative data set in Phase One provided information for further data collection involving follow-up telephone interviews and qualitative analysis. The research design provided triangulation since two sources—current and alumni presenters—provided quantitative and qualitative data, which were collected separately and then merged for analysis. This research was approved by the Human Research Ethics Committee of the University of Otago, New Zealand (Reference 17/116). The following sub-sections provide summaries of participants, survey instruments, the interviews, and data analyses.

Participants

There were two groups of participants recruited for this study: current presenters with the Science Caravan and alumni presenters. Current presenters included those at each of the 12 venues of one 2017–2018 Science Caravan tour. Approximately 60 high school students (16+ years old) or undergraduate students who volunteered to be presenters were invited to complete two surveys, and were asked for consent to be interviewed. The pre-presenting survey was administered on the morning of the first day of training, before training began (n = 764), and the post-presenting survey after presenters had finished on day six (n = 723). A month after the Science Caravan tour had finished at each location, 19 recent presenters were invited for follow-up interviews (10 high school students and nine university students).

The second group of participants included alumni who had been presenters with Science Caravan between 2005 and 2017. This group allowed investigation of the longer-term impact of being presenters. The recruitment of alumni presenters was conducted *via* the social media platform Facebook คาราวานวิทยาศาสตร์ page (Science Caravan) with 15,052 followers, and *Enjoy Science Career* page with 510 followers (the numbers of followers recorded on September 13, 2017). Invitations to participate in the survey, with a link to the online survey, were posted and advertised on the Facebook pages and resulted in 938 clicks on the survey link, with 726 (77.4%) completing the survey. Nineteen alumni presenters who had completed the survey were selected for follow-up interviews to investigate in-depth views of full-time workers and students at either the undergraduate or postgraduate level.

Survey Instruments

Three questionnaires were developed in English to explore the research questions:

- *Pre-presenting survey* for current presenters before participation in science communication training;
- *Post-presenting survey* for current presenters at the end of the final day of NSM Science Caravan; and
- *Alumni Survey* as a retrospective survey of alumni presenters.

Each survey was divided into four parts, and translated and administered in Thai *via* Qualtrics^{XM}, a web-based survey platform. Each survey began with demographic questions, followed by questions related to self-efficacy in science knowledge, attitudes towards science, and lifelong learning behaviors. Lifelong learning behaviors consisted of seven items focusing on free-time activities associated with science, with items developed by the researchers, informed by Venville et al. (2013).

We predicted that participation as a presenter would result in changes in four attitude dimensions: (I) *Future participation in science*, (II) *Value of science to society*, (III) *Self-concept about science*, and (IV) *Anxiety about science presenting*. Twenty-four items were included in the questionnaire; they were adapted from three sources (Weinburgh and Steele, 2000; Kind et al., 2007; Hillman et al., 2016) and developed to suit the particular Thai context. The items consisted of positive and negative statements in order to confirm that respondents were paying attention; items with five-point Likert-type responses were used, ranging from strongly agree to strongly disagree.

Exploratory factor analysis was conducted using SPSS Version 24 to summarize the 24 items into smaller sets of dimensions or scales (Pallant, 2011). In this study, three sets of statements, namely, "attitude towards science" (**Table 1**), "self-efficacy in science" (**Table 2**), and "lifelong learning behavior about science" (**Table 3**), were extracted. The Oblimin rotation for post-presenting surveys is presented here, revealing four factors for "attitude towards science" (**Table 1**) and one factor for "self-efficacy in science" (**Table 2**). Varimax rotation identified one factor for "lifelong learning behavior about science" (**Table 3**).

Cronbach's alpha is widely used to measure reliability and provide a measure of internal consistency of a set of items where all the subset of items in the survey are intended to measure the same concept (Tavakol and Dennick, 2011). Cronbach's alpha for all scales in each survey were acceptable, ranging from 0.73 to 0.89.

Interviews

All interviews were conducted between October 2017 and April 2018 by the first author. Each interview took approximately 15–30 min, and was recorded with permission. The interview questions were developed in English, with feedback from science communication researchers at the University of Otago, and then translated into Thai for Thai participants. The main questions probed attitudes towards science and science engagements to answer the research questions associated with participants' experience with the Science Caravan program.

Data Analyses

Paired t-tests were used to compare the differences between pre-presenting and post-presenting scores on attitude scales. A two-way, between-groups analysis of variance was used to examine the impact on the scores of attitudes towards science of the intervention of presenting with *Science Caravan,* gender, and education level. Wilcoxon sign rank test was employed to analyze items for *Lifelong learning about science* and compare results for pre-presenting and post-presenting. Hierarchical multiple

TABLE 1 | Summary of rotated factor analysis loading results >0.35 for 24 items on attitude towards science in the post-presenting survey.

Attitude item	Self-concept in science	Anxiety about science presenting	Value of science to society	Future participation in science
I can talk about science with others.	0.69	—	—	—
I learn science quickly.	0.69	—	—	—
I do very well in science studies.	0.67	—	—	—
I usually understand what people are talking about in science.	0.63	—	—	—
Science is easy for me.	0.59	—	—	—
I have a good feeling toward teaching science to school children.	0.43	—	—	—
I would enjoy studying science.	0.43	—	—	—
It makes me anxious about how I will deal with questions from students.	—	0.81	—	—
I worry about explaining the science content to school children.	—	0.72	—	—
It makes me nervous when school teachers ask me to explain science-related topics.	—	0.72	—	—
I feel tense when someone talks to me about science.	—	0.71	—	—
I become anxious when it is time to explain a science concept in front of my classmates.	—	0.66	—	—
Discoveries in science do not affect how I live	—	0.37	—	—
Science can produce useful technology	—	—	0.68	—
Science is useful in helping to solve the problems of everyday life.	—	—	0.61	—
Everyone should have some basic scientific knowledge.	—	—	0.57	—
It is exciting to learn about new things happening in science.	—	—	0.54	—
Science is not important to a country's development.	—	0.36	0.47	—
If I try hard, I can understand science.	—	—	0.46	—
People don't need to understand science because it does not affect their lives.	—	—	0.38	—
I would like to be a scientist.	—	—	—	0.79
I would like to be a science teacher.	—	—	—	0.68
I would like to have a job working with science.	—	—	—	0.58
I would like to study more science in the future.	—	—	—	0.50
Cronbach's alpha	0.86	0.82	0.73	0.75

TABLE 2 | Summary of rotated factor analysis loading results >0.35 for 3 items on Self-efficacy in science in the post-presenting survey.

Scale	Item	Factor loading
Self-efficacy in science	I have a lot scientific knowledge	0.75
	I can get good marks in science class	0.84
	My understanding of science is good	0.86
	Cronbach's alpha	0.85

TABLE 3 | Summary of rotated factor analysis loading results >0.35 for 7 items on Lifelong learning about science in the post-presenting survey.

Scale	Item	Factor loading
Lifelong learning about science	Visiting science museum, science center, zoo	0.62
	Watching science documentaries or TV show	0.77
	Reading science articles	0.80
	Browsing updated science news	0.83
	Searching for science information that is interesting to you	0.83
	Visiting website, Facebook, and blogs about science	0.81
	Participating in science events or public lectures about science or related topics	0.76
	Cronbach's alpha	0.89

regression was used to assess the ability of the combined scales of science attitudes (*Future participation in science, Value of science to society, self-concept in science,* and *Anxiety about science presenting*) and the scale for *self-efficacy in science knowledge* to predict intentions for *Lifelong learning about science*, after controlling for the influence of gender and education level.

To explore the intervention in relation to longer-term impact, 678 alumni presenters who had contributed in different time frames between 2007 and 2017 were asked to rate their agreement

TABLE 4 | Current presenters' attitudes towards science before and after presenting on 5-point, Likert-type scaled items, tested with paired sample *t*-test for the mean scores of current presenters (n = 690).

Scales	Pre-presenting	Post-presenting	*t*	*d*
	Mean (S.D.)	Mean (S.D.)		
Self-concept in science	3.52 (0.46)	3.78 (0.51)	15.58***	0.55
Future participation in science	3.43 (0.65)	3.62 (0.68)	9.25***	0.28
Value of science to society	4.11 (052)	4.25 (0.52)	8.03***	0.27
Anxiety about science presenting	3.08 (0.54)	2.81 (0.70)	10.98***	0.43

*Higher scores indicate more positive attitudes towards science with a maximum score of 5. The exception is the Anxiety about science presenting scale, where lower scores indicate less anxiety. N.B.: ***p < 0.001. d = Cohen's d effect size: >0.2, small; >0.5, medium (Sawilowsky, 2009).*

with the 24 attitude items on a five-point Likert-type. There was no difference in responses in any of the four attitude scales of those who presented in different years, indicating that the perception of alumni presenters from each year is similar. Respondents had similar experiences while presenting with the Science Caravan program, irrespective of which year they participated and so further analysis pooled results from all alumni presenters.

A thematic analysis approach as described by O'Leary (2010) was used to analyze 38 transcripts from interviews in order to interpret meaning in speech. Coding schemes were developed based on the research questions, and meaning was extracted from a sentence, paragraph, and message, and then similar meanings were grouped into codes (Kvale and Brinkmann, 2009; Daniel and Harland, 2018). The coding scheme was examined in English by all authors, using three translated transcripts. Experts recommend that the minimum acceptable inter-coder agreement is 80% (McHugh, 2012). Fleiss' kappa, a measure of inter-coder agreement, was also calculated to determine the level of agreement between two or more coders (Fleiss et al., 2003; Laerd Statistics, 2019). In this study, the value of kappa, $\kappa = 0.904$ (95% CI, 0.898 to 0.910), $p < 0.001$, showed that there was very consistent agreement between the coders (McHugh, 2012). Once intercoder reliability was determined to be adequate, the first author coded the remaining transcripts in Thai.

RESULTS AND DISCUSSION

In this section, we first present and discuss findings for changes in attitudes towards science after presenting. This is followed by findings on interest in lifelong learning and whether attitudes and self-efficacy can predict lifelong learning. In these sections, we first consider findings for current presenters and, second, those for alumni presenters. There is a discussion of study limitations. We present conclusions and implications of the findings for future work.

Changes in Attitudes About Science After Presenting

Current Presenters

Current presenters were asked their level of agreement with each statement on the 24 items of attitude scales before and after participation in the program. Paired-sample *t*-tests revealed the significant impact of presenting for all four subscales of the attitude scales (**Table 4**). Current presenters reported that they had increased *Self-concept in science* after their Science Caravan experience, indicating that the experience of presenting enabled self-perception of increased competence in science. Presenting with the Science Caravan offered opportunities to learn and acquire mastery through experience.

All of the high school students who presented were already studying science and most undergraduate students who presented were studying in STEM areas. As such, it was surprising that the scores for the pre-presenting "*Future participation in science*" scale were not as high as expected. This might be because two out of the four items in the scale relate to a specific career—"I would like to be a scientist" and "I would like to be a science teacher". Excluding these two items, the scores were higher for pre-presenting = 3.77 and post-presenting = 4.02. Moreover, the perceived difficulty of science (Osborne et al., 2003) after taking some courses might be a factor in decisions not to continue to study science in the future. However, in the post-presenting, the current presenters reported increased positive intentions about participating in science in the future. This is consistent with answers from in-depth interviews that being a presenter confirmed the feeling about existing academic or career plans. For example,

> I already liked science. Working in Science Caravan re-affirmed my feeling, it was right for me. Science is fun; therefore, I will study in science in the future.
>
> [Current presenter, male, undergraduate]

We thought there might have been a ceiling effect for the *Value of science to society* scale, which had the highest mean score of all scales, both pre-presenting and post-presenting. Current presenters already had a highly positive attitude about the value of science before presenting at Science Caravan. This is consistent with a previous study which found positive public opinions in Thailand about science and technology (National Statistics Office of Thailand, 2008). Nonetheless, there was a significant, if small increase in positive attitudes about the *Value of science to society* after presenting.

It is interesting that, on average, current presenters "neither agree nor disagree" (mean = 3.08) on the *Anxiety about science presenting* scale in the pre-presenting survey (**Table 4**). This might be because they had no experience regarding those items, for example, "*It makes me anxious about how I will deal with questions from students*". However, after their presenting experiences, respondents reported decreased *Anxiety about science presenting* in post-presenting. This indicates that the experience of presenting helped to reduce science anxiety when faced with a situation of explaining science to others. This is consistent with answers from in-depth interviews in that the value of feedback from NSM staff and visitors is likely to help reduce anxiety. For example,

> At that time, a former director of [XXX] School, came in when I was about to pack up. He asked me a lot of questions. I answered him based on my knowledge while James (NSM staff) was there. He admired that I could solve specific problems well, making me feel good.
>
> [Current presenter, female, undergraduate]

Although current presenters reported that they had less *Anxiety about science presenting* after their Science Caravan experience, the scores still indicated some *Anxiety about science presenting*. In interviews, some presenters explained that they felt they had insufficient knowledge regarding the exhibits. They reported that lack of sufficient knowledge made them feel nervous and anxious about explaining and answering questions from visitors. For example, a current presenter (male, high school student) said, "Sometimes I got questions when I did not have enough information, and I was afraid to give a wrong explanation." A female high school student said "I was afraid that I could not explain to [visitors] well enough to make them understand, and answer the questions."

The anxiety of some presenters was exacerbated when they were asked questions by teachers, especially some that were very challenging. Anecdotal observations by the first author indicated that some teachers appeared to aim to show off their own knowledge to presenters or their students. This is not surprising given the context of a predominately didactic education system where teachers are expected to be the masters (Tatar and Horenczyk, 2000). Comments from two female current presenters were that: "Teachers asked me about in-depth details" (undergraduate student) and "Some teachers made me anxious" (high school student).

The current presenters experienced the feeling of being a significant person by providing an exciting science experience, as well as inspiring visitors about science, especially young school children who were the majority of visitors. The program provided an opportunity for presenters to obtain encouragement from visitors' positive feedback.

Attitudes can be developed from three elements—cognitive information, affective information, and behavioral information (Zanna and Rempel, 2008). The unique experience of presenting with the Science Caravan provided most presenters with a largely positive experience of explaining science to audiences, related to both affect and behavior. As a result, their attitudes towards science were more positive after presenting. As Olson and Zanna (1993) pointed out, a new affective experience can be a powerful source of influence, particularly for affect-based attitudes.

Alumni Presenters

Alumni presenters' responses showed the greatest effect of presenting for the scales *Self-concept in science* (**Figure 2A**) and the *Value of science to society* (**Figure 2C**), with approximately 80% of respondents reporting positive impact of their previous participation. Retrospective reporting of changes in *Future participation in science* showed a smaller change (**Figure 2B**). However, a still high 70% of respondents reported that their feeling about a continued future participation in science areas was much or a little improved, while 24% of respondents felt it was about the same after presenting.

Even though half of the respondents reported that they had less *Anxiety about science presenting*, this scale had the smallest percentage change when compared to the other three scales (**Figure 2D**). A quarter of respondents rated "about the same" in anxiety about science presenting and approximately a quarter felt increased anxiety. These results were consistent with the results from the current presenters that their anxiety about science presenting still existed after the 6 days of their experience with the program.

Alumni comments in the end of the survey indicated that participants valued their experience as a presenter. For example: "It was worthwhile being a presenter" [Alumni presenter, female], and "I was so proud and happy working with the Science Caravan" [Alumni presenter, male].

Changes in Female and Male Participants' Attitudes Towards Science

There was a significant interaction between gender and the presenting intervention in relation to *Anxiety about science presenting* (**Table 5**). While being presenters resulted in reports of lower levels of *Anxiety about science presenting* for both male and female students, there was a greater effect for female presenters who had a less negative attitude on the *Anxiety about science presenting* scale after their experience (**Figure 3**). The 6 days of experience presenting with the Science Caravan had a larger impact for female presenters than their male counterparts in fostering self-confidence in science presentation and reducing their anxiety about science presenting.

There were significant main effects of gender and of presenting for *Future participation in science*, but no interaction effect (**Table 5**). There was no significant difference in this scale between men and women before their involvement as a program presenter; however, after contributing as a program presenter, women had more positive response in *Future participation in science* than men, t (688) = 2.26, $p < 0.05$.

Alumni male presenters reported a higher *Self-concept in science* than female presenters and both reported higher *Self-concept in science* (4.1–4.2) than did current presenters post-presenting (3.7–3.8). In the long-term period, there was no significant difference between male and female alumni

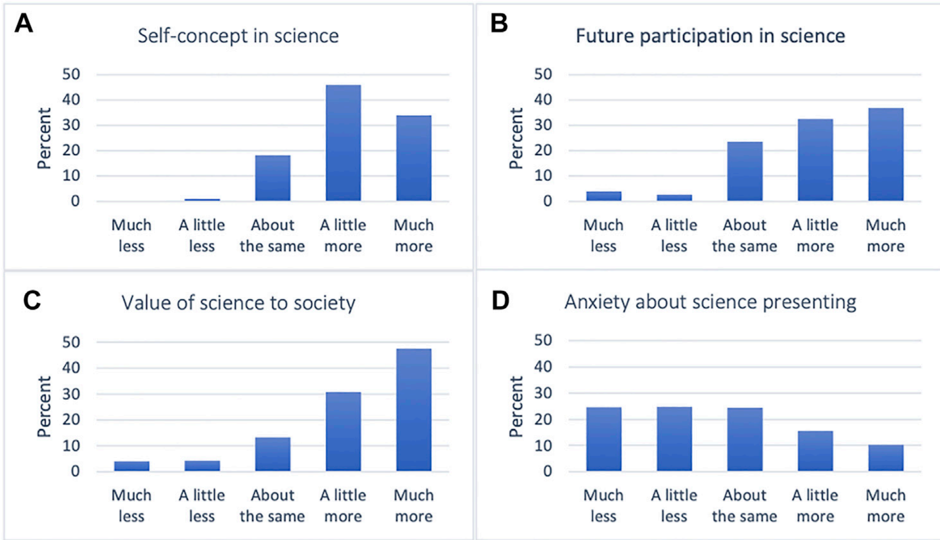

FIGURE 2 | Alumni presenters' retrospective rating (percentage; n = 678) of how being a presenter had impacted their attitudes towards science in four scales: Self-concept in science **(A)**; Future participation in science **(B)**; Value of science to society **(C)**; and Anxiety about science presenting **(D)**.

TABLE 5 | Results of a two-way ANOVA with regard to gender of current presenters (n = 690).

Scale	Df	Mean square	F	Sig.	Effect size	R^2
1) Self-concept in science (7 items)						
Intervention	1	1,003.5	85.74***	0.000	0.059	—
Gender	1	17.75	1.52	0.218	0.001	—
Intervention*Gender	1	15.32	1.31	0.253	0.001	0.071
Error	1,376	11.7	—	—	—	—
2) Value of science (7 items)						
Intervention	1	277.38	21.32***	0.000	0.015	—
Gender	1	33.12	2.52	0.112	0.002	—
Intervention*Gender	1	3.39	0.26	0.611	0	0.02
Error	1,376	13.13	—	—	—	—
3) Future participations (4 items)						
Intervention	1	159.13	22.55***	0.000	0.016	—
Gender	1	48.07	6.81**	0.009	0.005	—
Intervention*Gender	1	2.56	0.36	0.547	0	0.024
Error	1,376	7.06	—	—	—	—
4) Anxiety in science (6 items)						
Intervention	1	691.71	48.98***	0.000	0.034	—
Gender	1	72.8	5.15*	0.023	0.004	—
Intervention*Gender	1	58.03	4.11*	0.043	0.003	0.051
Error	1,376	14.12	—	—	—	—

*N.B.: *p < 0.05, **p < 0.01, ***p < 0.001.*

presenters in their attitudes about science for the other three attitude scales.

Increased Interest in Lifelong Learning Activities After Presenting

Current Presenters

After presenting, there was a significant increase in current presenters' interest in most of the listed science-related activities in their free time, z = 8.78, p < 0.001, d = 0.76 (**Figure 4**). Among science-related activities, "*Browsing updated science news*" showed the highest increase in respondents' interest.

In contrast, there was a decrease on intention to *Visit science museum, science center, zoo* and *Watching science documentary or TV show*, z = 2.32, p < 0.05, d = 0.19. Given presenters had just spent an intensive week in a travelling science center, it could be their interest was sated and their focus shifted to different activities. It is interesting to note that presenters studying with a science major changed their preferences for obtaining science knowledge. They were more likely to favor active learning seeking science knowledge

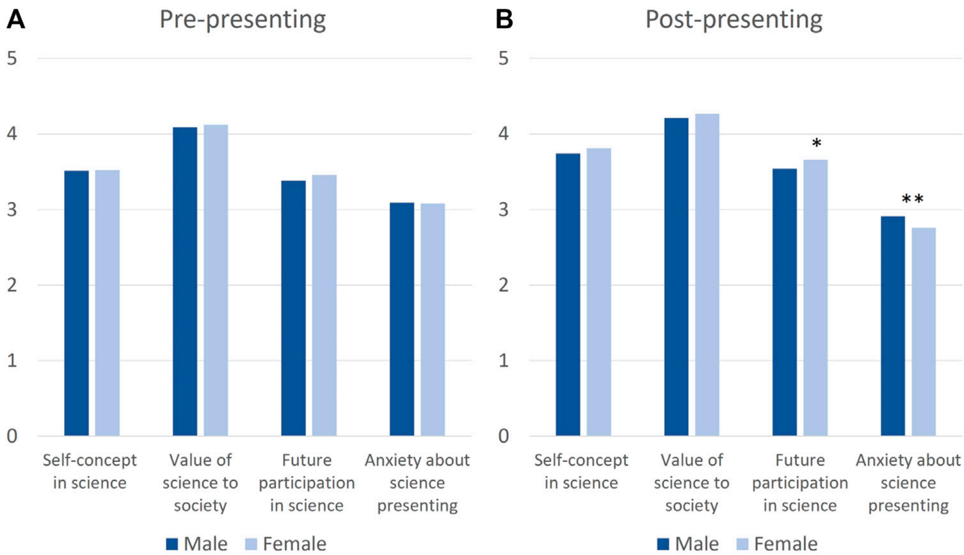

FIGURE 3 | Current female and male presenter responses on four attitude scales before **(A)** and after **(B)** presenting. Higher scores indicate more favorable attitudes towards science with the exception of the science anxiety in presenting scale, where higher scores indicate more science anxiety. Independent sample *t*-tests were conducted to detect significant differences. N.B.: $^*p < 0.05$, $^{**}p < 0.01$.

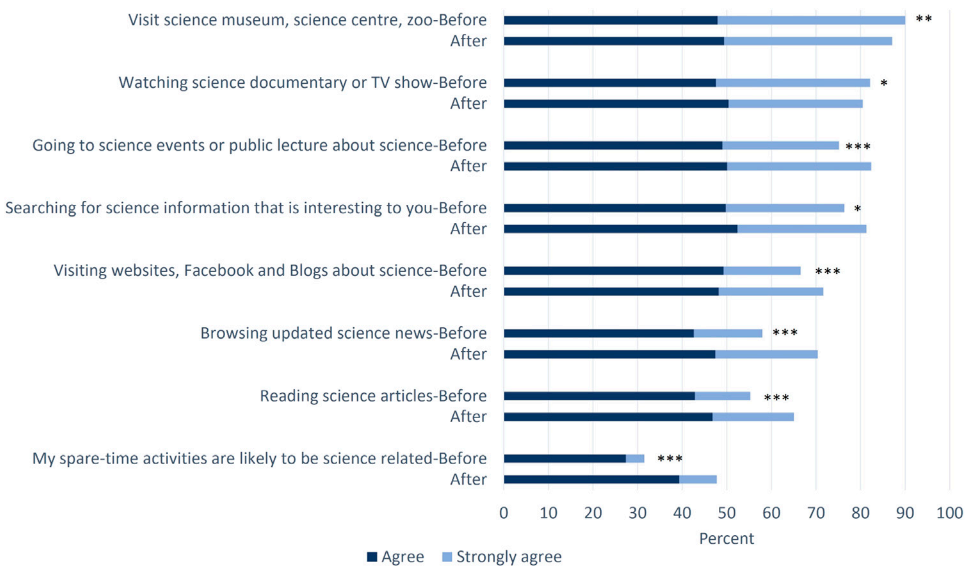

FIGURE 4 | Current presenters' interest in lifelong learning, assessed by response to "I am interested in these activities" from pre-presenting and post-presenting questionnaires (high school students, $n = 380$ combined with undergraduate science majors, $n = 223$). N.B.: $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

that is of interest to them rather than passive learning, receiving information by watching science documentaries and TV shows, or visiting science museums. Although their interest in these activities significantly decreased, over 80% of respondents rated these items highly in both the pre-presenting and post-presenting surveys.

Alumni Presenters

In contrast to current presenters, over 90% of alumni presenters reported increases in their interest to *Visit science museum, science center, zoo* (**Figure 5**). In addition, over 75% of respondents agreed that they were more interested in all of the listed lifelong learning activities. Almost half of respondents agreed that presenting

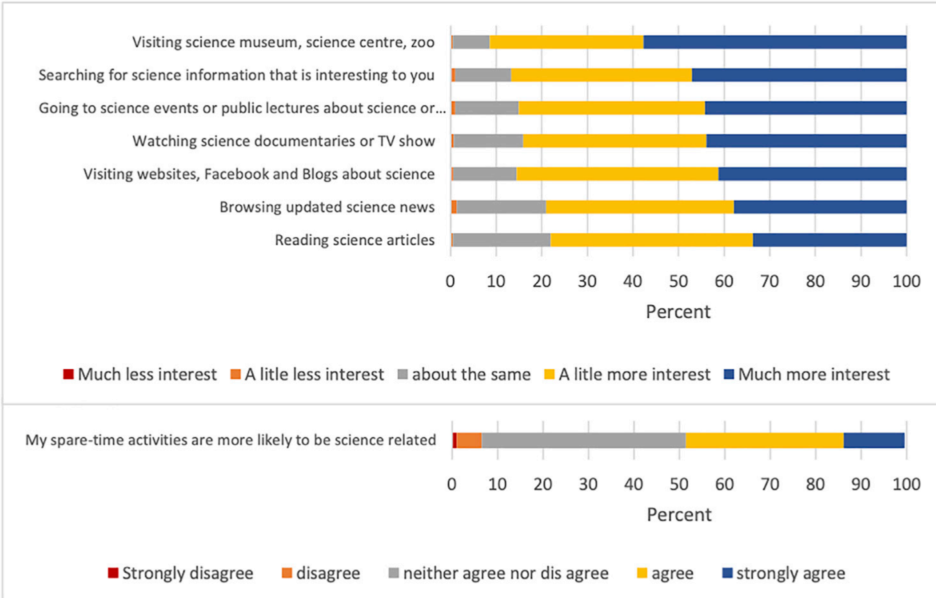

FIGURE 5 | Alumni presenters' views on impact of presenting on their interest in lifelong learning activities in science.

increased their inclination for spare time activities related to science, indicating that many respondents expected to maintain interest in ongoing engagement with science-related activities.

Qualitative Findings for Both Groups

The qualitative findings are consistent with the quantitative results, which provide clear evidence that participation in presenting enhanced interest in science-related activities for both current and alumni presenters. For example, one current presenter said:

> In my free time, I liked to watch movies. After being a presenter, I am more curious. It changed me from watching movies to watching documentaries about science instead. I already liked to watch documentaries about animals. Being a presenter inspired me to learn more. [I] got more curious about science.
>
> [Current presenter, female, undergraduate]

Furthermore, results from alumni presenters confirmed that they were still interested in the science-related activities up to 10 years after their experience of presenting. For example:

> I am interested in many leisure activities. If speaking of science-related activities, I like to read research articles about physics on websites and follow up all about science and technology updates. Because I love to know about the advancement of technology, and I want to update my knowledge.
>
> [Alumni presenter, male, undergraduate]

The quotes above indicate that presenters maintain lifelong learning behaviors related to science. The results support Hidi and Renninger (2006), that people engage with an object of their interest after interaction between the person and relevant content. According to Hidi and Renninger (2006), interest is "a motivational variable that refers to a psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time" (p. 112). People have their interest triggered when experience catches their attention (Renninger and Bachrach, 2015). One explanation may be that the positive, novel experience of being a presenter triggered their interest in science-related activities. In addition, the new experience with positive feelings enhanced presenters' self-concept in science. There is a feedback loop as positive feelings can influence the development of interest, and interest shapes self-concept (Hannover, 1998 cited in; Wender, 2004).

Attitudes towards Science and Self-Efficacy as Predictors of Lifelong Learning Behavior

As discussed earlier, the Theory of Planned Behavior (Ajzen, 1991) states that an individual's intention is a predictor of engaging in a behavior, and that this intention is influenced by attitudes towards the behavior, subjective norm, and perceived behavioral control. According to Ajzen (2002), the concept of perceived behavioral control aligns with the notion of self-efficacy. It was predicted that two influencing constructs would be impacted by the presenting experiences: *Attitudes towards science* and *Self-efficacy in science knowledge.* Hierarchical multiple regression used these two constructs,

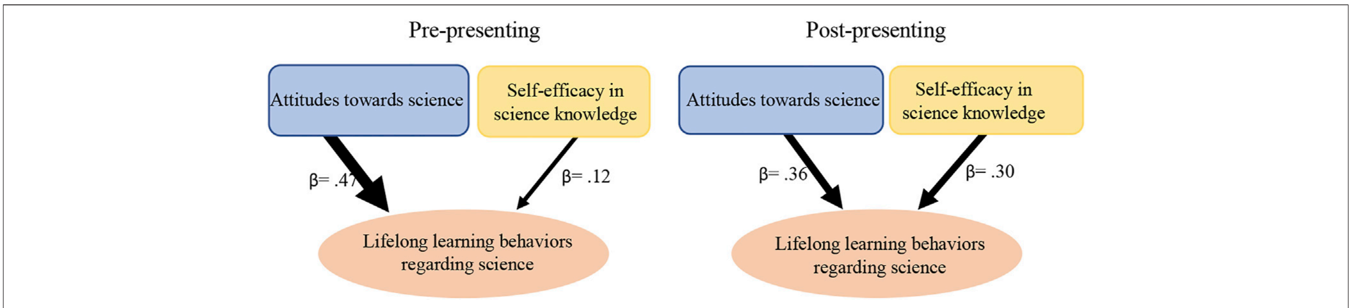

FIGURE 6 | Results of current presenters' hierarchical regression analyses with interest in lifelong learning activities about science as criterion variables (*n* = 684).

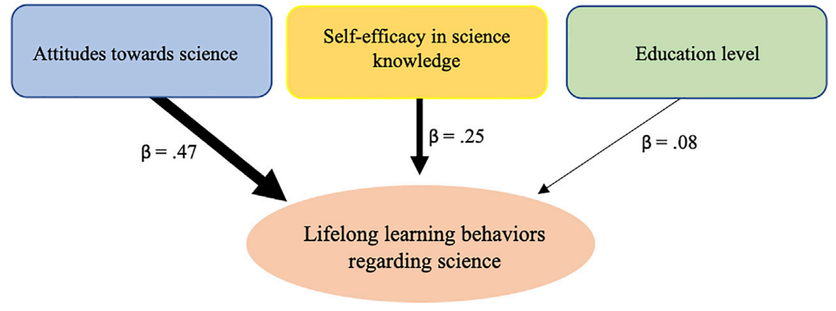

FIGURE 7 | Alumni presenters' hierarchical regression analyses with lifelong learning behaviors regarding science as criterion variables (*n* = 678).

gender and education level as variables to predict the impact of contribution as a presenter on behaviors related to *Lifelong learning about science.*

Current Presenters

In the pre-presenting survey, *Attitudes towards science,* as measured in this study's scales, made the strongest unique contribution to explaining intention for *Lifelong learning about science* with current presenters, demonstrated by hierarchical multiple regression (**Figure 6**). The relationship was positive; those having positive feelings in *Attitudes towards science* and *Self-efficacy in science knowledge* while being presenters were more likely to intend to practice lifelong learning behaviors related to science. Gender and education level were entered at step 1, explaining 0.4% of the variance in *Lifelong learning behavior about science*. After entry of the *Attitudes towards science,* and *Self-efficacy in science knowledge* at step 2, the total variance explained by the model as a whole was 28%, $F(4{,}678) = 66.17$, $p < 0.001$. The two constructs explained an additional 27.7% of the variance in *Lifelong learning about science*, after controlling for gender and education level [R^2 change = 0.28, F change (2,678) = 130.51, $p < 0.001$]. In the final model, two constructs were statistically significant, with *Attitudes towards science* being a better predictor (beta = 0.47, $p < 0.001$) than *Self-efficacy in science knowledge* (beta = 0.12, $p = 0.001$).

In the post-presenting survey, hierarchical multiple regression of results from current presenters revealed similar results to those pre-presenting (see **Figure 6**). The proposed model yields two significant variables explaining 32% of variance of *Lifelong learning about science* [$F(4{,}677) = 79.39$, $p < 0.001$]. Again, *attitudes towards science* was the strongest predictor (beta = 0.36, $p < 0.001$), followed by *Self-efficacy in science knowledge* (beta = 0.30, $p < 0.001$). In the post-presenting results, *Self-efficacy in science knowledge* was a stronger predictor than in the pre-presenting results. This suggests that increase of positive *Self-efficacy in science knowledge* after presenting added to the ability of this construct to predict behavioral intention towards lifelong learning in science.

Alumni Presenters

Alumni presenters' experiences of presenting had long-term impacts on their self-reported actual lifelong learning behavior (see **Figure 7**). The proposed model yields three significant predictors explaining 38% of the variance of lifelong learning behavior scores [$F(4{,}671) = 103.55$, $p < 0.001$]. *Attitudes towards science* was the strongest predictor (beta = 0.47, $p < 0.001$) followed by *Self-efficacy in science knowledge* (beta = 0.25, $p < 0.001$). Education level was a third, weak predictor, unlike in the model for current presenters, where no significant effect of education level on prediction was found. The direction of the relationship suggests that having more positive feelings regarding *Attitudes towards science, Self-efficacy in science knowledge,* and lower education level (younger age) as a presenter significantly contributed to intentions towards lifelong learning behaviors.

Attitudes towards science form from integration of experiences with various aspects of science (Gardner, 1975; Bennett, 2003). Attitudes one holds as a result of these experiences may influence subsequent decisions and behaviors (Bennett, 2003). People have their interest triggered when an experience focuses their attention (Renninger and Bachrach, 2015). One possible explanation of increased interest in lifelong learning behavior noted by presenters in Science Caravan was the development of interest from positive feelings. Interest shapes self-concept (Hannover, 1998, cited in Wender, 2004). The results from alumni presenters support findings of Hidi and Renninger (2006) that interaction with particular content sparks students' engagment with an object of interest.

Study Limitations

This study had several limitations. Firstly, the findings are based on self-reports. Secondly, while all current presenters responded to the surveys (100% response rate), only 726 out of 8,000 alumni presenters completed the alumni survey (9.1%), indicating the potential for sample bias in responses of alumni presenters. Because there was no contact list of alumni presenters, it was impossible to contact them more directly. Facebook pages: คาราวานวิทยาศาสตร์ (Science Caravan), and Enjoy Science Career page were the primary avenues to reach alumni presenters and recruit participants. It seems likely that alumni presenters following these pages hold more favorable opinions about the Science Caravan program. These alumni presenters may have been more diligent in maintaining contact with the program and staff, and more receptive to responding to a survey about the program. This is an important consideration in determining potential bias (Sickler and Johnson, 2009), as are the characteristics of non-respondents (Robson, 2011).

Further indication of a biased sample of alumni presenters is that unlike current presenters, all alumni presenters who responded to the survey were involved in science studies or careers. Therefore, a long-term impact of participating in Science Caravan on presenters who had not been studying science could not be examined in this study. There was no negative feedback about the program obtained from respondents. While there was no evidence to indicate that the non-responding alumni had more negative perspectives, a conservative view would assume that the overall impact on all alumni presenters may not be as strong as the results reported in this study. Nonetheless, response from current presenters included non-science students who reported positive impacts of presenting.

CONCLUSION

There are many studies about attitudes of audience members after outreach programs or visiting an informal setting environment (Mamlok-Naaman et al., 2005; Luehmann, 2009; Salmi et al., 2016; Yawson et al., 2016; Vennix et al., 2018). Research investigating presenters' attitudes through participation in outreach activities is more limited (Larsen, 1994; Ferry, 1995; Toolin, 2003). This paper reports impacts of participation as a presenter in Science Caravan on attitudes to science and behavioral intentions for lifelong learning.

Both current and alumni presenters at Science Caravan reported positive impacts of their participation as presenters on their attitudes towards science. Attitudes were measured using four scales: *Future participation in science*, *Self-concept in science*, *Value of science to society*, and *Anxiety about science presenting*. Results of the pre-presenting surveys demonstrate that current presenters already possessed positive attitudes towards science. These findings are consistent with the results from previous surveys that have shown that many in Thailand are knowledgeable and positive about the importance of science and technology, even if they make a decision not to study science or take on scientific careers (National Statistics Office of Thailand, 2008; Yuenyong and Narjaikaew, 2009). Nevertheless, the brief experience of being Science Caravan presenters had positive effects in all four scales of science attitudes. This demonstrates that an intensive 6-day outreach experience can increase positive attitudes towards science.

Changes in behavioral intentions related to lifelong learning were investigated in this study. When asked about their interest in daily spare-time activities related to science, current presenters agreed that they were more interested in many activities related to lifelong learning after the 6-day program. Results from alumni presenters confirmed that they still felt more interested in the science-related lifelong learning activities years after presenting, providing evidence of an actual change in behavior, albeit self-reported and retrospective.

The results of this study demonstrate the value of using the Theory of Planned Behavior to explore science outreach. Attitudes towards science and self-efficacy were measured in this research. In this study, students were more likely to choose to continue to engage in science-related activities in their spare time when they reported feeling competent and having positive attitudes towards science. There is a positive relationship between attitudes towards science, self-efficacy and interest, and these lead to choosing science-related activities in lifelong learning. Future research could examine the effect of the subjective norm as another important factor that influences behavioral intention in the Science Caravan context.

This study provides evidence of a positive relationship between attitudes towards science and interest in spare-time science activities. The development of positive attitudes towards science can motivate students' interest in science education and science-related careers (Crawley and Coe, 1990; Norwich and Duncan, 1990). Interest is a psychological construct that can be used to predict an intention to participate in science-related activities in the future (Ainley and Ainley, 2011). We suggest that an increase of students' interest and participation in science activities in their spare time can lead to an increase of intended lifelong learning behavior about science. Several studies have found that interest is an important factor for choices of education and occupations in STEM areas (Venville et al., 2010; Bøe, 2012; Venville et al., 2013). This study revealed that presenters' experience with Science Caravan provided a valuable experience that helped them to develop interest related to science. Furthermore, this study revealed that presenters' positive attitudes towards science could be developed by a short-term, intensive experience as a presenter.

Implications and Future Research

The outreach learning atmosphere and experience was perceived positively by volunteer presenters. We suggest that educators, teachers, and schools should consider adding presentation and science outreach activities to their curriculum. In particular, activities with an out-of-school experiential learning element could be especially valuable supplements to curriculum for science students and pre-service teachers. The activities should enable performance and mastery of experience for the students, focusing on the understanding and application of science, connecting to the curriculum and daily life.

Findings from this study support the value of involvement of science undergraduate students in the delivery of public engagement activities. This aligns with findings of Mackay et al. (2020); as public engagement should be the business of all scientists, this approach would help to ensure that more budding scientists are adequately prepared to engage with the public about science using diverse and effective techniques. In order to ensure that science communication training and practice is offered to trainee scientists, we recommend that informal science learning institutes and universities cooperate to develop and offer programs in this area to their students.

Future research could determine the proportion of presenters continuing study in science-related disciplines in higher education. Although this study used surveys and interviews of alumni presenters to investigate the longer-term impact of the program, a longitudinal study was not within its scope. As mentioned above, the distribution of an online questionnaire survey to alumni presenters *via* Facebook is likely to have introduced sample bias. None of the non-science alumni presenters responded to the survey. A longitudinal design could examine the longer-term impact of contributing as a presenter with the Science Caravan program.

Research has pointed out that "attitudes toward science change with exposure to science, but that the direction of change may be related to the quality of that exposure" (Gogolin and Swartz, 1992, p. 500). This study offers evidence that there is a positive relationship between attitudes towards science and interest in science activities, indicating that Science Caravan provides quality exposure.

Many studies about outreach programs have shown that science outreach activities can positively influence visitors' attitudes and motivation (Bell et al., 2009). Far fewer have examined impact on presenters. This report is a significant contribution in that respect. This study demonstrates that a short-term, intensive experience of presenting with Science Caravan provided a valuable experience that helped presenters develop more positive attitudes towards science and increased their intentions of future participation in lifelong learning about science.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Human Research Ethics Committee of the University of Otago, New Zealand (Reference 17/116). Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

NS, NL, and RS-S contributed to conception and design of the study. NS organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Evaluating Changes in Experimentation, Critical Thinking, and Sense of Wonder in Participants of Science North's In-School Outreach Programs

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The aim of this study was to evaluate and report on the impact of an in-school science outreach program on children's self-reported science knowledge, engagement, and skills through a case study of the Science North in-school outreach program "Mission to Mars." A logic model method was used to outline the specific inputs, outputs, and measurable outcomes of the program. The program outcomes evaluated in this study were (1) experimentation skills, (2) critical thinking skills, and (3) sense of wonder. Results from pre-post surveys demonstrated that participants had increased program topic knowledge. Students self-reported positive emotions toward science more frequently following exposure to the program. Students' sense of wonder toward science and toward space also increased post-program. This increase in positive emotion toward science could, in the short-term, increase student motivation toward science, which could lead to lasting interests in science in the long-term. Only a small number of students reported an increase in experimentation and critical thinking skills post-program. These skills take time to develop, and the single short-term program evaluated in this study may not have given students enough exposure to these skills for them to experience and show a noticeable change. The results of this study can provide informal science institutions like science centers with important insights into the potential learning impact of their in-school outreach programs, and can be used to improve current and future programs. Other organizations with in-school science outreach programs can benefit from using the methodology in this study to evaluate their programs, as this research includes a combination of innovative data collection methods such as concept maps to determine what students associate with the word "science," and the use of an emoji scale to capture student emotions toward science. From a larger perspective, this study evaluating the impacts of in-school science outreach could demonstrate the potential benefits and outcomes of this unique area of informal learning, further solidifying the importance of incorporating these inquiry-based programs into classrooms.

Keywords: evaluation, in-school science outreach, experimentation, critical thinking, knowledge, science center, informal science

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INTRODUCTION

It is now well accepted that science learning is a continuous, on-going process with elements that span beyond the walls of formal school classrooms (Dierking et al., 2003; Stocklmayer et al., 2010; Falk and Dierking, 2019). Science learners engage with science through interacting with the natural world, lived experiences, prior knowledge, and everyday interactions (Dierking et al., 2003; Bell et al., 2009; Falk and Dierking, 2018a), and much of science learning occurs in informal environments such as libraries, museums, after-school programs, and by engaging with digital media (Falk et al., 2007; Rennie, 2014; Reiss, 2020). Recent curriculum reforms are encouraging the integration of inquiry-based methods into classrooms, however from lack of training and funding, to political and cultural barriers, there are still many hurdles for teachers to successfully implement them (Davis, 2003; Schwarz and Stolow, 2006; Stocklmayer et al., 2010). The current model of formal science education remains bound by curriculum constraints, transmission-based teaching methods, a hierarchical nature, and a focus on imparting specific knowledge that is assessed for sequence (Davis, 2003; Corrigan et al., 2018). Informal science learning however, places emphasis on learner interest, and is usually voluntary, inquiry-based, and self-directed (Dierking et al., 2003; Rennie, 2007; Fenichel and Schweingruber, 2010).

In order to fill gaps within traditional school-based science learning, informal science learning experiences can be integrated into formal learning environments (Malcolm et al., 2003; Stocklmayer et al., 2010). In fact, many education researchers are calling for more collaborations between schools and informal science institutions (Bevan and Semper, 2006; Bell et al., 2009; Bevan et al., 2010; Stocklmayer et al., 2010; Falk and Dierking, 2019). These collaborations could reduce barriers faced by schools by creating more equity and access to informal science programs and their benefits (Bell et al., 2009; Bevan et al., 2010). Echoing this, Falk and Dierking (2018b) have recently suggested an "ecosystem-based" approach to science education, which would give learners access to a network of different intersecting science learning opportunities that include formal schooling with a variety of other free-choice learning opportunities.

Students typically access free choice or informal science learning opportunities through supplementary class room experiences (like field trips, activities, or events), collaborations between formal and informal institutions to create changes in curriculum, out-of-school programs, teacher professional development, and updated and increased infrastructure (Bevan et al., 2010). Field-trips are the most common form of free-choice science experiences and these have been researched extensively for student and teacher outcomes (Bell et al., 2009, examples, Kisiel, 2005; DeWitt and Osborne, 2007; DeWitt and Storksdieck, 2008). As mentioned by Stocklmayer et al. (2010), schools face many barriers supporting class visits to out-of-school sites such as time restraints, liability, and expenses. These authors instead suggest a "third space" where students can engage with informal science within their own schools. The potential for a particularly unique type of science learning experience that blurs the lines between schools and their community is that of in-school science outreach programs. In-school science outreach is an engagement opportunity that is offered by science center or university outreach teams, private organizations, or after-school clubs (Stocklmayer et al., 2010). These programs are unique as they require a special connection to formal science learning and usually adhere to curriculum guidelines to some degree, to enrich classroom learning (Stocklmayer et al., 2010). The goal of many science outreach initiatives is to reach under-represented and under-served audiences in various communities to increase science literacy and science skills, and to enable these groups to potentially pursue a career in science, technology, engineering, or math (STEM) (Komoroske et al., 2015).

While in-school science outreach may fit within the framework of a science learning ecosystem, there is still a lack of evidence demonstrating the concrete outcomes of these types of programs (Bevan et al., 2010). In order for these in-school outreach programs to be fostered and seen as valuable, student outcomes need to be measured in a way that aligns with the goals of both school learning goals (i.e., knowledge gain), and informal institutional goals (i.e., engagement and positive affective outcomes) (Bevan et al., 2010). There are some examples of research demonstrating students' increased knowledge in a particular subject following outreach programs (Komoroske et al., 2015), while other studies focus specifically on career and skill outcomes for students (Beck et al., 2006; Laursen et al., 2007). Many of these studies focus on in-school science outreach conducted by universities and their graduate students or researchers, leaving a gap in our understanding of the impacts of in-school science outreach delivered by informal science institutions like science centers.

Considering the lack of research and evaluative studies demonstrating the outcomes of in-school science outreach offered by science centers, this study uses a systematic approach to evaluate an in-school science program through a case study of one of Science North's outreach programs. Science North is a science center in Sudbury, Ontario that delivers science education experiences to schools across Northern Ontario that are distant from the main science center. We, the authors, work collaboratively with Science North as partners in Laurentian University's Science Communication graduate program.

In order to evaluate one of Science North's in-school outreach programs, we needed to determine intended outcomes anticipated for participants in the program. This was done using a logic model—a systematic approach that illustrates the links between goals, activities, and principles of a project or program and creates measurable outcomes for evaluation (Bonney et al., 2011). To identify outcomes, we referred to the National Science Foundation's (NSF) Framework for Evaluating Impacts of Informal Science Education and Outreach, which we will refer to as the NSF Framework (Friedman, 2008). The NSF Framework was created to assist practitioners and program developers with the evaluation of informal programming, which includes impact categories that are commonly found in logic models for informal programs. The framework identifies six impact categories: (1) knowledge, (2) engagement, (3) attitude, (4) behavior, (5) skills, and (6) other (Friedman, 2008). These impact categories are common learning outcomes identified in the development of informal science programs, and are used by many researchers to evaluate program impacts (Beck et al., 2006; Devictor et al., 2010; Komoroske et al., 2015; Jensen, 2014). For example, a summary of evaluation reports from afterschool STEM programs by Afterschool Alliance (2011) outlined three similar types of outcomes determined in STEM afterschool programs: improved attitudes toward STEM fields and careers, increased STEM knowledge and skills, and higher likelihood of pursuing a STEM career. Several of the NSF impact categories also align with Science North program goals of increasing experimentation and critical thinking (NSF impact category of skills), and igniting a sense of wonder (NSF impact category of engagement). The NSF impact category of knowledge mirrors a common outcome supported by schools, which tend to focus on students gaining knowledge guided by curriculums.

With this literature in mind, a logic model was developed to define measurable goals mirroring NSF impact categories from the NSF Framework (Friedman, 2008) to answer the following research question:

What are the cognitive, skill-related, and affective outcomes for students participating in a Science North in-school outreach program?

To answer this, we conducted a summative evaluation of Science North's "Mission to Mars" in-school outreach program to assess if, and to what extent, students in the program engage in three specific outcomes laid out in the logic model:

(A) Experimentation
(B) Critical Thinking
(C) Sense of wonder

MATERIALS AND METHODS

Creating a Logic Model

Figure 1 outlines the logic model developed for Science North's in-school outreach programs delivered to provincially funded schools, which was developed using the evaluation guide by the Center for the Advancement of Informal Science Education (Bonney et al., 2011).

The first column of the logic model describes all of the *Inputs* required for in-school outreach programs. These *Inputs* include yearly organizational funds and key financial stakeholders that support the programs. Also included in the inputs are the school boards, schools, school administration, and teachers directly involved in scheduling in-school outreach program days and supervising students that participate in programs. Within Science North, *Inputs* include program staff that directly support in-school outreach programs in all stages of program development and implementation.

The second column describes the *Outputs*, which includes the activities offered by Science North and the participants of these programs. Science North offers 50-min curriculum linked programs to provincially funded elementary schools (JK to Grade 8) across Northern Ontario.

The third column, *Outcomes,* describes the intended measurable short-term impacts, and the potential long-term impacts. Overall, Science North delivers in-school outreach programs to engage typically under-served students in Science, Technology, Engineering, and Math (STEM). These programs are intended to make an impact on students in three impact categories as guided by National Science Foundation's Framework (Friedman, 2008):

Knowledge:

- Increased knowledge of STEM related topics covered in programs
- Increased knowledge of STEM related careers covered in the programs

Skills:

- Increased experimentation skills
- Increased sense of inquiry
- Increased critical thinking ability

Engagement and Attitude:

- Ignite a sense of wonder (curiosity) in students toward STEM
- Increase interest in STEM related careers
- Increase positive attitude toward STEM

Long-term, Science North aims to have an impact on students' likelihood of pursuing STEM related careers in the future, and to give students a life-long continued interest in STEM and continued science literacy skills that will be used throughout a student's lifetime.

Evaluating Program Outcomes

Approach

Our summative evaluation investigated the changes in student behavioral, cognitive, and/or affective outcomes after participating in a Science North in-school outreach program. The mixed-methods study took place over 2 weeks in three schools, during which we collected both qualitative and quantitative data. The study design is a quasi-experimental pre-post design, comparing the data from the same group of students before and after an initiative has been implemented, without a control group (O'Leary, 2017). Quantitative data was used to capture the change in students' self-reported cognitive, behavioral, and affective outcomes after the program. Open-ended questions were used to collect qualitative data to explore the experience of the participants.

Sampling and Recruitment

The population that participates in Science North in-school outreach programs are school-aged students in grades JK—Grade 8 (ages 3–14) who attend provincially funded schools in Northern Ontario. Considering this large age range, this study specifically evaluated the change in Grade 5 and 6 students (ages 10 and 11 years old), who engaged in the Grade 5/6 "Mission to Mars" program offered by Science North. The sample can be described as representative of

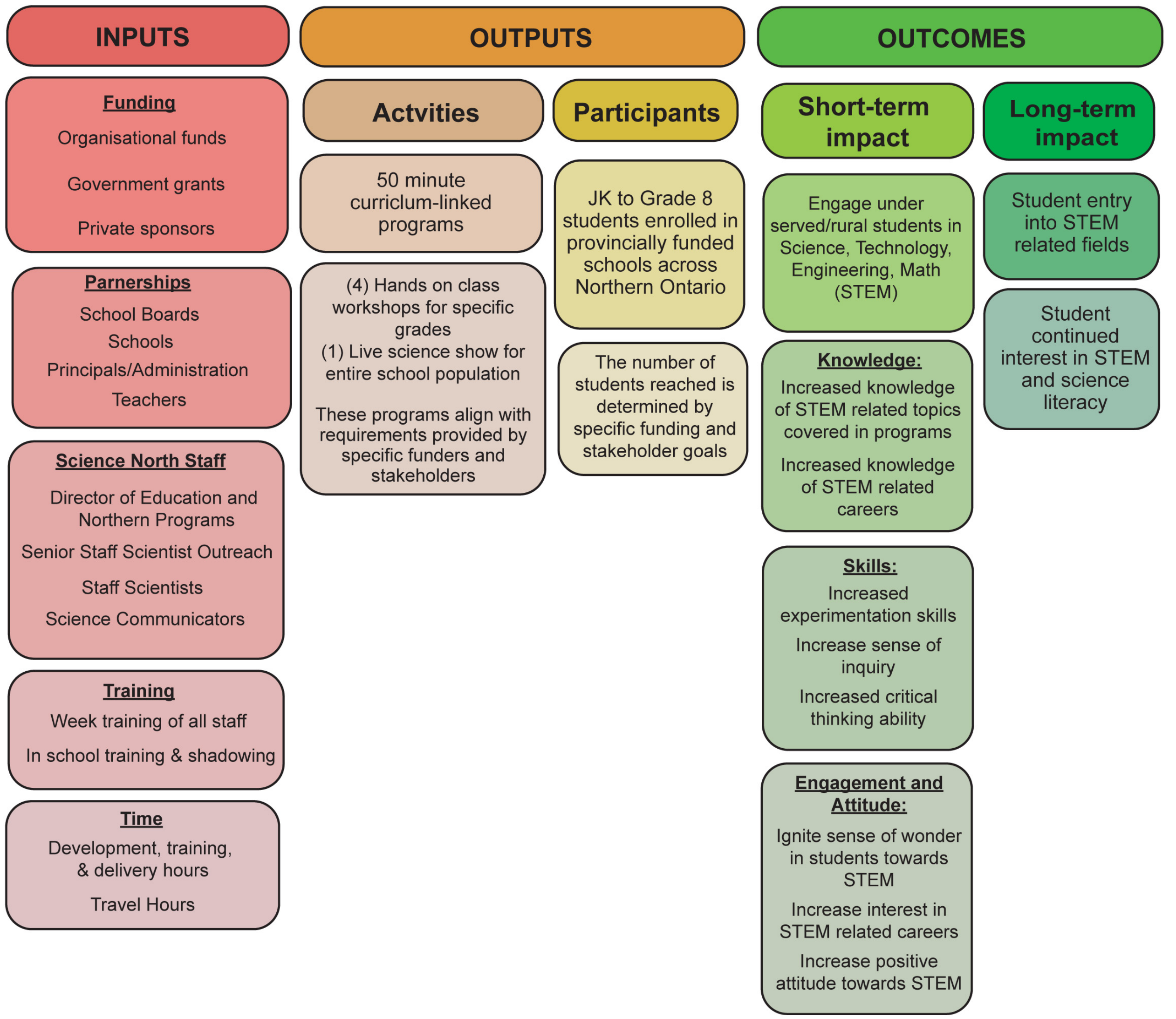

FIGURE 1 | Science North provincially funded in-school outreach initiatives logic model. This logic model demonstrates the inputs and outputs of Science North in-school outreach programs as well as the measurable outcomes that were evaluated throughout this study.

Grade 5 and 6 students, ages 10 and 11, who typically participate in Science North's in-school outreach programs in Northwestern Ontario.

This study was carried out after full research ethics board review and approval from the Laurentian University Research Ethics Committee (refer to **Supplementary Material** for research ethics certificate of approval). This study followed all protocols required when researching vulnerable human participants, including all necessary approvals, consents, and assents. Several measures were put in place to ensure confidentiality and anonymity of the subjects throughout the study.

Following school board approval, three schools agreed to participate in the study. From those schools, eight Grade 5 and 6 teachers were contacted and five agreed to participate. Of the 126 students within the five classes that agreed to participate, 45 students provided the required consent and assent forms and therefore were the participants of this study.

Data Collection

Surveys and Distribution

Pre-post surveys were used in this study as they are commonly used to evaluate the changes in cognitive, affective, and behavioral outcomes resulting from instructional intervention (Dugard and Todman, 1995). The surveys were modified from successful survey instruments from previous studies for students in this age range (refer to **Supplementary Material** for survey instrument), and included anonymous identifier questions to ensure pre and post surveys could be matched to the same participant, and ensuring confidentiality.

Students were given the pre-survey 1 week prior to the delivery of the "Mission to Mars" program. One week following program delivery, students completed the post-survey. Only the surveys from students with parental consent and personal assent were used in data analysis.

In-School Outreach Program

The "Mission to Mars" program was designed and delivered fully by Science North Staff Scientists and is directly linked to the provincial Science and Technology curriculum for the intended age range. This program was offered to schools as a part of Science North's traveling outreach program that are delivered to classes across Northern Ontario.

The "Mission to Mars" program aims to provide students with basic knowledge of the planet Mars, and gives insight on why humans take part in space exploration through the use of technology, like rovers. Participants in the program are given the opportunity to practice critical thinking and experimentation skills through the planning, designing, testing, and rebuilding their own Mars rover sensor protection device.

In hopes of promoting a sense of wonder within students participating program, Science North program staff begin the session by providing the class with a virtual reality tour of the surface of Mars. Using the virtual reality headsets, students see 360° images of Mars and the Mars rover Curiosity. Students are then given a challenge in which they are told that they are working for a space agency that is sending a rover to Mars to gather planetary information. The Science North program instructor advises the students that the rover has a sensor that relays important information about the Mars rover, including the gravitational force upon landing. In groups, the students are tasked to protect this sensor as the launching acceleration and landing on Mars can damage the sensor and break it before it sends any information to Earth. Critical thinking skills are tested as each group is given a budget to purchase materials (cotton balls, cups, elastics, etc.), and are asked to create a design sheet for their unique sensor protection device. Students are then challenged to build and launch their sensor held within the constructed protection device with a leaf blower through a launching tube. Each sensor is Bluetooth connected to a cell phone that provides each group with the live updates of the gravitational force that the sensor is experiencing. Experimentation skills are tested as students are asked to reduce the gravitational force that the sensor experiences each time it is launched by changing their design and re-launching. Additional challenges, such as parachute attachments, are added depending on the progression of the class. The program concludes with discussions summarizing the student findings while having them discuss how the experiment would be different if it took place in space, and not in a classroom (variables to consider like gravity, weather, etc.).

Survey Instrument

The survey began with a concept map question with *science* as the central concept. Students were asked to write and/or draw what they think of when they hear the word science. Concept maps were used because they can provide insight into students' mental models, which reflects experiences, beliefs, and understanding students may have of a topic, how this information is represented, and how these ideas are organized in students' minds (Kinchin et al., 2000; Halford, 2014).

To capture how they feel about science, students were asked to choose one of seven emojis that had a corresponding affective word describing the emojis. The emojis and connected affective words used were chosen from a study by Gallo et al. (2017), which demonstrated their effectiveness in representing emotional response to stimuli in children ages 8–11 (refer **Supplementary Materials** for the emoji scale within the student survey). Emoji use for child research has been validated as a child-centered visual research method that can assist with allowing children's opinions and experiences to be heard (Fane et al., 2018). Using emoji scales in informal science program evaluation has not been explored extensively, allowing us to give commentary on the use of this method for this purpose. Emoji photos used were designed by OpenMoji.

The remaining questions in the survey were adapted from the formal evaluation of the 4-H Science Initiative by Mielke et al. (2002). Questions one through five were Noyce enthusiasm scale questions adapted from Mielke et al. (2002), used to determine interest in science and assessing the change in sense of wonder. Questions six and seven were taken from the Children's Science Curiosity scale (Harty and Beall, 1984), and focus on curiosity and interest in relation to space science. Questions 8–11 assessed critical thinking, and were adapted by Mielke et al. (2002) from Perkins and Mincemoyer (2002). The final set of questions was adapted from the Science Process Skills Inventory (Arnold and Bourdeau, 2009), specifically for ages 9–12, and assessed the outcome of experimentation.

Data Analysis

Concept Map

The data collected from the concept map with *science* as the central concept was coded using thematic analysis. Using the coding methods outlined in Braun and Clarke (2006), we began by reading all concept map answers to familiarize themselves with the data and to generate initial codes. Each concept map was transcribed in a final list of all words, phrases, and drawings—drawings were transcribed into a word or phrase based on semiotic analysis using part of Charles S. Peirce theory of icon, index, and symbol. In this theory, an icon is interpreted as what it directly resembles, an index is considered for its true connection to an object, and a symbol is interpreted as representative of a symbolic meaning (Burks, 1949). In one of the most recent studies investigating the use of semiotics at the primary school level, the most frequently used indicator by children was the icon (Türkcan, 2013). For this reason, and in alignment with scope of this study, the drawings were only analyzed as icons; images were interpreted at the physical level for the object they appeared to represent.

The final themes were guided by the NSF Framework (Friedman, 2008) for evaluating informal science programs which includes the impact categories of knowledge, skills, attitude, engagement, behaviors, and other. The theme of knowledge was divided into sub-categories of six common science subjects: biology, chemistry, earth science, physics, technology, and space. The theme of engagement was split into two sections of positive and negative emotions. Each word or drawing that was coded as affective was further defined as either positive or negative using the open source opinion lexicon by NRC Word-Emotion Association Lexicon (Mohammad and Turney, 2013). For an example of knowledge icon interpretation, if a student drew what appeared to be a rocket, this was coded as the word "rocket," which was subsequently added to the space category within the NSF knowledge theme. For an example of engagement icon interpretation, if a student drew what appeared to be a sad face (circle, two eyes, and mouth with sides declined), this was coded as "sad," and was added to the negative emotion category.

Emoji Scale

Responses were analyzed quantitatively based on the frequency at which each emoji was chosen in the pre and post surveys. Frequencies were recorded as percentages and capture occasions when students chose multiple emojis.

Science Engagement and Skills

Each group of science engagement questions were analyzed based on the survey instrument they were adapted from, and the intended outcome they assessed. If students chose more than one answer, or if they did not give an answer for any of the 11 Likert questions or the five Science Process Skills Inventory questions, the answer was reported as "undecided."

Questions one through five from the Noyce Science Enthusiasm survey instrument (Mielke et al., 2002) were assessed as indicators of science enthusiasm, or sense of wonder. Questions six and seven from Children's Science Curiosity Scale (Harty and Beall, 1984) were assessed for the Science North outcome of sense of wonder. Questions 8–11, were used to assess critical thinking. The final five questions were used to assess the Science North outcome of experimentation. **Table 1** summarizes the survey instrument's sources, the NSF Framework impact category (Friedman, 2008), and Science North outcomes these instruments assessed. Cronbach alpha was calculated for each survey section with 3 or more statements to determine internal consistency. Pre and post evaluation data was converted to numerical data, and means were calculated for each set of questions by variable, found in **Table 2**. Note: Lower numerical mean indicates that students were more likely to agree with the statements, i.e., "strongly agree" = 1, "agree" = 2, "disagree" = 3, and "strongly disagree" = 4.

Table 3 summarizes the mean findings pre and post survey. Paired *t*-tests were run for each variable to conduct statistical significance.

TABLE 1 | Survey instruments used to evaluate Science North In-school outreach program outcomes.

Survey instrument	Question (s)	NSF outcome assessed (Friedman, 2008)	Science North outcome assessed	Sources
Concept map	Write and/or draw what you think of when you hear the word science.	Knowledge, Skills, Engagement, Other	Knowledge, Skills, Engagement, Other	Researcher developed
Emoji scale 7 emoji options	How does science make you FEEL? Circle one (1) emoji.	Engagement	Sense of wonder	Researcher developed, Emoji choice by Gallo et al. (2017)
Noyce enthusiasm for science scale Agree, strongly agree, disagree, and strongly disagree options	- Science is something I get excited about - I like to work on science activities - I am curious to learn more about science - I like to see how things are made (for example, ice-cream, TV, iphone) - I get excited to find out that I will be doing a science activity	Engagement	Sense of wonder	Mielke et al., 2002
Children's science curiosity scale Agree, strongly agree, disagree, and strongly disagree options	- I like to talk about planets and stars - I would like to experiment with the gadgets inside the space station	Engagement (specifically toward space topics)	Sense of wonder (toward program topic)	Harty and Beall, 1984
Critical thinking scale Agree, strongly agree, disagree, and strongly disagree options	- I find it easy to say what I think about a challenge - I think of possible results or what might happen before I make a decision - I can figure out the best way to deal with something that needs to be solved - I keep my mind open to different ideas when planning to make a decision	Skills	Critical thinking	Adapted from Perkins and Mincemoyer (2002)
Science process skills inventory Yes or no options	- I can make a chart or picture to show information - I can do an experiment to answer a question - I can write down information correctly - I can tell others how to do an experiment - I can explain why things happen in an experiment	Skills	Experimen-tation	Modified from Arnold and Bourdeau (2009)

TABLE 2 | Mean survey instrument responses for participants pre and post survey.

Survey instrument	Mean PRE	Mean POST
Noyce enthusiasm for science	1.84	1.71
Science curiosity	1.92	1.74
Critical thinking	2.11	2.06
Science process skills Inventory	1.3	1.23

Lower numerical mean indicates that students were more likely to agree with the statements, i.e., "strongly agree" = 1, "agree" = 2, "disagree" = 3, and "strongly disagree" = 4.

RESULTS

Concept Map

Of the 45 surveys, eight students did not complete the concept map pre-program, and seven students did not post-program delivery. Using thematic coding, the text and drawings from the concept maps were coded into four of the NSF impact categories from the NSF Framework (Friedman, 2008): (1) knowledge, (2) engagement, (3) skills, and (4) other. The knowledge category had the highest frequency of responses out of all of the categories, and also had the largest change in frequency from pre to post survey with an increase of 34 occurrences. Within the skills category, there was an increase of 11 occurrences from pre to post survey. The largest change that occurred within skills was in the sub-category of "experimentation," which increased by seven occurrences from pre to post survey. **Table 4** displays the concept map codes and frequencies of occurrence pre and post survey.

The outcome of knowledge was split into six sub-categories: chemistry, technology, physics, earth science, biology, and space. The frequency of occurrences for each of these can be found in **Figure 2**. Chemistry had the highest frequency with 33 occurrences pre and post. Space showed the largest change in frequency with an increase of 19 occurrences from pre to post survey.

The NSF Framework (Friedman, 2008) impact category of engagement saw the second largest increase in occurrences from 18 in the pre-survey to 43 in the post-survey. The Engagement sub-categories of positive and negative emotions included an increase for positive emotions by 29 from pre survey to post survey. The frequency of a negative emotion decreased by four. These changes can be found in **Figure 3**.

Emoji Scale

All respondents on both the pre and post survey answered the emoji scale question, and several students chose multiple emojis. There were 51 emojis selected in the pre survey and 49 selected in the post survey. Prior to the program, the majority of students reported feeling excited (43% of responses) and happy (24% of responses) toward science. After the program, there was an increase of 16.1% of students who reported feeling excited toward science, which was the largest change across all the emoji choices from pre to post survey. In addition, there was a decrease of 5.1% in students who reported being happy, a decrease of 7.6% of students who reported being confused, a decrease of 1.6% in students who reported being bored, and a decrease of 5.7% in students who reported being shocked. No students chose the emoji representing sadness in either the pre or post survey.

No students reported feeling angry in the pre survey, however two students did post-program—an increase of 4.1%. The changes in percentage of emoji selection from pre to post survey can be found in **Figure 4**.

Science Engagement and Skills

Questions one through five, taken from the Noyce Enthusiasm Scale (Mielke et al., 2002), were statements assessed alongside each other as seen in **Figure 5**. In these questions, frequencies "strongly agree" and "agree" represent students who reported a high or moderate enthusiasm toward science, while "disagree" and "strongly disagree" represent students who reported little or no enthusiasm toward science. Cronbach alpha for these statements were calculated to be 0.83 and 0.83 for pre and post survey, respectively.

Following the "Mission to Mars" program, there was an overall increase in students who reported a high level of enthusiasm toward science, and a decrease in students who reported a moderate level of enthusiasm. The largest change occurred for the statement "I like to see how things are made," which had a decrease of seven occurrences of "disagree," and the frequency of "strongly agree" increased by eight. Generally, all statements showed a decrease in students who reported having little to no enthusiasm for science post-program.

Statements six and seven were adapted from the Children's Science Curiosity Scale (Harty and Beall, 1984) and were assessed alongside each other in **Figure 6**. In these questions, frequencies of "strongly agree" and "agree" represent students who reported a high or moderate curiosity toward science, while "disagree" and "strongly disagree" represent students who reported little or no curiosity toward science. Cronbach alpha for these statements were calculated to be 0.83 and 0.83 for pre and post survey, respectively.

Responses for both statements showed that students had curiosity for science prior to the program, which increased post-program. Prior to the program, students agreed with the statement "I like to talk about planets and stars," the most, with 29 out of 45 students choosing "agree" or "strongly agree." When comparing both statements, "I would like to experiment with gadgets in the space station" had a greater number of students who agreed or strongly agreed in comparison to "I like to talk about planets and stars" in both the pre and post survey. There were more students however who strongly agreed or agreed that they like to talk about planets and stars from pre to post survey, as the frequency increased by nine. Both statements saw an increase in the number of students who agreed and strongly agreed, and a decrease in students who disagreed, strongly disagreed, and who were undecided from pre to post survey.

The four statements found in **Figure 7** were used to assess students' critical thinking, adapted from Mielke et al. (2002). In these questions, frequencies of "strongly agree" and "agree" represent students who reported high or moderate scientific critical thinking skills, while "disagree" and "strongly disagree" represent students who reported little or no scientific critical

TABLE 3 | Numerical participant survey responses with mean values pre and post survey.

		Noyce enthusiasm for science						Science curiosity			Critical thinking					Science process skills inventory					
Student code	**Survey**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Mean**	**Q6**	**Q7**	**Mean**	**Q8**	**Q9**	**Q10**	**Q11**	**Mean**	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Mean**
109AR	1	2	2	3	3	2	2.4	2	2	2	3	3	2	2	2.5	1	1	1	1	1	1
021 × 0	1	4	2	4	2	3	3	3	2	2.5	4	5	3	5	4.3	1	1	1	1	2	1.2
116JP	1	3	2	3	2	2	2.4	3	2	2.5	3	2	2	2	2.3	1	1	3	1	1	1.4
3131LI	1	3	2	3	2	3	2.6	2	5	3.5	2	2	2	2	2	2	1	1	1	2	1.4
3013SA	1	2	2	2	1	2	1.8	3	1	2	2	3	1	1	1.8	1	1	1	1	2	1.2
104AA	1	1	1	1	2	1	1.2	1	2	1.5	2	2	2	1	1.8	1	1	1	1	1	1
214MA	1	2	2	2	3	2	2.2	1	1	1	2	3	1	3	2.3	1	1	1	1	1	1
5323OT	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	2	2	2	2	1	1.8
1127EP	1	2	2	2	2	2	2	2	2	2	3	5	5	2	3.8	1	1	1	3	1	1.4
0227AA	1	2	1	2	2	1	1.6	1	2	1.5	3	2	1	2	2	1	1	1	1	1	1
2027LP	1	1	2	2	2	1	1.6	2	2	2	2	2	2	1	1.8	1	1	1	1	1	1
1023JE	1	2	2	1	1	2	1.6	4	3	3.5	2	2	1	2	1.8	1	1	1	1	1	1
1110GE	1	1	1	1	2	1	1.2	2	1	1.5	2	1	2	1	1.5	1	1	3	1	1	1.4
0220XA	1	2	5	2	2	2	2.6	2	2	2	3	5	2	2	3	1	1	1	3	3	1.8
109SH	1	2	1	2	1	2	1.6	1	1	1	3	3	2	2	2.5	1	1	1	1	1	1
2127AN	1	1	1	1	1	1	1	2	1	1.5	2	1	1	1	1.3	1	1	1	1	1	1
107KI	1	4	3	3	2	3	3	3	2	2.5	4	4	3	4	3.8	2	2	2	2	2	2
017XA	1	1	2	2	3	1	1.8	2	1	1.5	2	2	1	1	1.5	2	1	1	1	1	1.2
1022AA	1	2	2	1	1	2	1.6	1	1	1	2	2	2	2	2	1	1	1	1	1	1
121GA	1	2	2	2	2	1	1.8	3	1	2	2	1	2	1	1.5	1	1	1	1	3	1.4
1214SO	1	2	1	1	1	2	1.4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1225DA	1	2	2	1	1	2	1.6	2	5	3.5	2	1	2	1	1.5	2	1	2	1	1	1.4
1113OR	1	2	2	2	1	1	1.6	1	1	1	3	2	2	2	2.3	1	3	3	2	2	2.2
1029AA	1	2	1	1	1	1	1.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0125MU	1	1	1	1	1	1	1	2	1	1.5	3	1	3	3	2.5	1	1	1	2	1	1.2
3127RA	1	2	2	2	3	2	2.2	3	1	2	3	2	2	3	2.5	1	1	1	1	1	1
11PCM	1	2	2	2	1	2	1.8	2	1	1.5	2	2	3	2	2.3	1	1	1	1	1	1
529AP	1	1	2	2	1	2	1.6	1	2	1.5	2	1	2	1	1.5	1	1	2	1	1	1.2
5212LE	1	1	1	1	1	1	1	1	2	1.5	1	2	1	1	1.3	1	1	1	2	1	1.2
1218WO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	3	3	3	2.6
129GN	1	2	2	2	1	2	1.8	3	2	2.5	2	2	2	2	2	3	3	1	1	3	2.2
026AB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	2	1.6
0226NA	1	2	1	2	2	1	1.6	3	1	2	2	2	3	2	2.3	2	1	1	1	2	1.4
1026S1	1	1	2	1	2	1	1.4	1	1	1	1	2	2	1	1.5	1	1	1	1	1	1
2225EA	1	2	1	2	2	2	1.8	3	2	2.5	3	3	2	1	2.3	2	1	1	1	2	1.4
025MU	1	4	2	2	3	3	2.8	2	3	2.5	2	2	3	1	2	1	1	1	1	1	1
116XO	1	2	1	2	2	2	1.8	3	2	2.5	2	3	2	2	2.3	1	2	1	1	2	1.4
01712KL	1	1	1	2	2	2	1.6	3	1	2	2	2	2	1	1.8	1	1	1	1	1	1
0123MA	1	2	2	3	2	2	2.2	3	2	2.5	3	3	3	2	2.8	1	1	2	2	2	1.6
1028PU	1	2	2	2	2	2	2	3	2	2.5	2	2	3	2	2.3	1	1	1	2	1	1.2
206EO	1	1	1	1	2	1	1.2	2	1	1.5	1	2	2	2	1.8	1	1	1	1	1	1
0121KO	1	3	3	3	2	3	2.8	2	3	2.5	2	2	2	2	2	1	1	1	1	1	1
0116XI	1	4	4	4	2	4	3.6	4	1	2.5	5	1	2	2	2.5	1	1	1	1	1	1
0125CD	1	2	2	2	1	2	1.8	2	1	1.5	2	2	2	1	1.8	1	1	1	1	1	1
211JE	1	1	2	3	1	3	2	4	2	3	4	4	4	4	4	2	1	2	1	2	1.6
Means		2	2	2	2	2	**1.8**	2	2	**1.9**	2	2	2	2	**2.1**	1	1	1	1.3	1	**1.30**
109AR	2	2	2	2	1	1	1.6	2	1	1.5	2	2	1	2	1.8	1	1	3	1	1	1.4
021X0	2	3	2	3	2	3	2.6	3	3	3	3	5	3	2	3.3	1	1	1	1	2	1.2
116JP	2	3	2	2	2	2	2.2	2	2	2	3	2	3	2	2.5	1	1	1	1	1	1

(Continued)

TABLE 3 | (Continued)

		Noyce enthusiasm for science						Science curiosity			Critical thinking					Science process skills inventory					
Student code	**Survey**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Mean**	**Q6**	**Q7**	**Mean**	**Q8**	**Q9**	**Q10**	**Q11**	**Mean**	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**	**Mean**
3131LI	2	2	2	2	2	3	2.2	2	2	2	3	3	2	2	2.5	1	1	1	1	2	1.2
3013SA	2	2	2	2	1	2	1.8	2	1	1.5	3	2	2	2	2.3	1	1	2	1	1	1.2
104AA	2	1	1	1	1	1	1	1	1	1	1	2	2	1	1.5	1	1	1	1	1	1
214MA	2	1	1	1	2	1	1.2	1	1	1	2	1	2	1	1.5	1	1	1	1	1	1
5323OT	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	2	1	2	2	1	1.6
1127EP	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2.5	1	1	1	2	2	1.4
0227AA	2	1	1	2	1	1	1.2	1	2	1.5	2	2	1	1	1.5	1	1	1	1	1	1
2027LP	2	2	2	2	1	2	1.8	2	1	1.5	2	2	2	2	2	1	1	1	1	1	1
1023JE	2	1	1	1	1	1	1	2	1	1.5	2	2	2	1	1.8	1	1	1	1	1	1
1110GE	2	1	1	1	1	1	1	2	1	1.5	2	2	2	1	1.8	1	1	3	1	3	1.8
0220XA	2	5	5	2	2	5	3.8	2	2	2	5	5	5	5	5	1	1	1	3	3	1.8
109SH	2	2	2	3	1	2	2	1	1	1	3	3	2	2	2.5	1	2	1	1	2	1.4
2127AN	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
107KI	2	2	1	2	1	2	1.6	2	1	1.5	2	2	1	1	1.5	1	1	1	1	2	1.2
017XA	2	1	1	1	1	1	1	2	1	1.5	2	2	1	1	1.5	1	1	1	1	1	1
1022AA	2	1	1	1	1	1	1	1	1	1	2	2	2	1	1.8	1	1	1	1	1	1
121GA	2	2	1	2	2	2	1.8	3	1	2	2	2	2	2	2	1	1	1	1	3	1.4
1214SO	2	2	1	1	1	1	1.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1225DA	2	1	2	1	1	2	1.4	2	1	1.5	2	3	2	1	2	2	1	1	1	1	1.2
1113OR	2	4	2	2	2	1	2.2	1	1	1	2	3	2	2	2.3	2	1	2	2	3	2
1029AA	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0125MU	2	1	1	1	1	1	1	2	1	1.5	1	2	4	2	2.3	1	1	1	2	1	1.2
3127RA	2	2	1	2	3	2	2	2	2	2	2	3	3	2	2.5	1	1	1	2	1	1.2
11PCM	2	3	2	1	1	2	1.8	2	1	1.5	3	2	3	2	2.5	2	1	1	1	1	1.2
529AP	2	2	1	2	1	2	1.6	3	1	2	2	2	2	1	1.8	1	2	1	1	1	1.2
5212LE	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1218WO	2	1	1	1	3	5	2.2	2	5	3.5	2	5	1	1	2.3	1	3	1	3	1	1.8
129GN	2	2	2	2	1	2	1.8	3	2	2.5	2	2	3	2	2.3	1	1	2	1	1	1.2
026AB	2	1	1	1	1	1	1	2	1	1.5	2	1	2	2	1.8	1	1	1	2	2	1.4
0226NA	2	2	1	3	1	2	1.8	3	1	2	2	2	3	2	2.3	2	1	2	1	1	1.4
1026S1	2	1	2	1	1	2	1.4	1	1	1	2	2	2	1	1.8	1	1	1	1	1	1
2225EA	2	2	1	1	4	2	2	2	2	2	4	4	2	2	3	1	1	1	1	1	1
025MU	2	3	2	3	3	2	2.6	2	2	2	3	2	1	3	2.3	1	1	1	1	1	1
116XO	2	1	1	1	1	1	1	2	2	2	2	1	1	2	1.5	1	1	1	1	1	1
01712KL	2	1	1	2	2	1	1.4	2	1	1.5	2	1	2	1	1.5	1	1	1	1	1	1
0123MA	2	2	2	2	2	2	2	3	2	2.5	3	3	3	2	2.8	1	1	2	2	2	1.6
1028PU	2	2	2	2	2	2	2	3	2	2.5	3	3	3	3	3	2	1	1	2	1	1.4
206EO	2	1	1	1	1	1	1	2	1	1.5	1	2	2	2	1.8	1	1	1	1	1	1
0121KO	2	3	2	3	2	3	2.6	2	2	2	2	2	2	2	2	1	1	1	1	1	1
0116XI	2	4	2	3	2	3	2.8	4	1	2.5	1	1	1	2	1.3	1	1	1	1	1	1
0125CD	2	2	1	1	1	2	1.4	2	2	2	1	2	2	1	1.5	1	1	1	1	2	1.2
211JE	2	3	3	3	2	3	2.8	3	3	3	3	2	3	3	2.8	1	2	1	2	2	1.6
Means		2	2	2	2	2	**1.7**	2	2	**1.7**	2	2	2	2	**2.1**	1	1	1	1	1	**1.2**

thinking skills. Cronbach alpha for these statements were calculated to be 0.66 and 0.4 for pre and post survey, respectively.

Overall, the majority of students reported that they had critical thinking skills before and after the program. The statement which students agreed or strongly agreed with the most was that they can keep their minds open to different ideas when planning to make a decision, and this statement saw the largest increase from pre to post survey. The number of students who strongly agreed or agreed that they find it easy to say what they think about a challenge increased, while students who think of possible results or what might happen before they make a decision remained the same from pre to post. This statement saw the highest number of undecided remaining at three students from pre to post. There was a decrease in

TABLE 4 | Concept Map NSF impact categories and frequency of codes pre and post survey.

NSF impact category (Friedman, 2008)	**Science categories and example answers**	**Frequency of codes Pre-survey**	**Frequency codes post-survey**
Knowledge: Awareness, knowledge, understanding of STEM concepts and careers	Biology - Brain, animals, plant, worm, life, dinosaur	4	11
	Chemistry - Potions, chemicals, beaker, explosion, periodic table, matter, molecules, safety goggles	33	33
	Earth Science - Gold, earth, rocks, volcano	4	6
	Physics - Magnet, math	4	3
	Space - Rocket, universe, mars, rover, planets, astronaut	6	25
	Technology - Coding, computers, robot, VR	4	11
	TOTAL	55	89
Engagement: Engagement of interest in STEM concepts, processes, or careers	Positive emotions - Fun, happy, excited, enjoyable, awesome	8	37
	Negative emotions - Sad, bored, confused	10	6
	TOTAL	18	43
Skills: Procedural aspects of knowing	Experimentation	3	10
	Inquiry	7	11
	TOTAL	10	21
Other	Bill Nye, information, scientist,	12	9

the number of students who agreed or strongly agreed that they can figure out the best way to deal with something that needs to be solved.

The final five survey questions asked students to agree or disagree with statements that assessed experimentation skills, the results of which can be found in **Figure 8**. Overall, the majority of students (ranging from 30 to 41 responses out of 45) reported that they could do all five experimentation actions. The action that most students reported being able to accomplish is doing an experiment to answer a question. The action that students reported being able to do the least was explaining why things happen in an experiment. From pre to post survey, there was an increase in students reporting that they could complete four of the five experimental actions. The only experimental action with a decrease was being able to tell others how to do an experiment. Of all of the survey questions, these experimentation statements had the highest frequency of students selecting "undecided" as their responses.

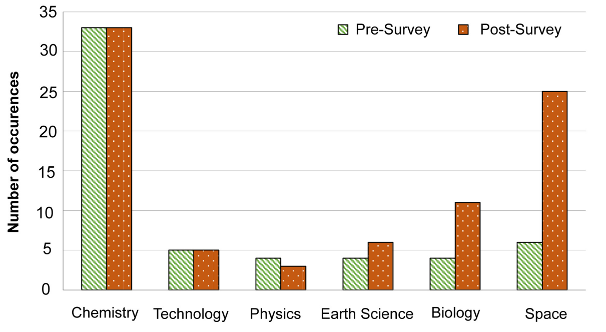

FIGURE 2 | Frequency of knowledge sub-categories. Results depicting the frequency of science subjects mentioned in the concept map question both pre and post survey. These subjects were coded through thematic analysis of question 1, which asked students to "write and/or draw what you think of when you hear the word science."

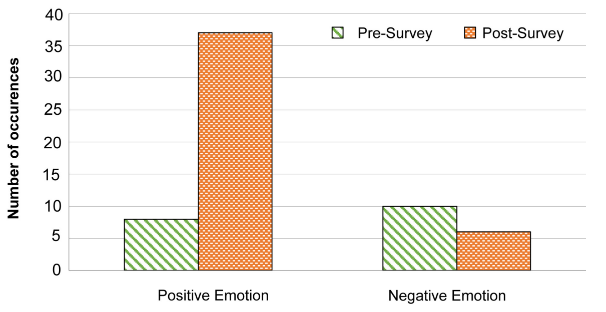

FIGURE 3 | Frequency of engagement sub-categories, positive and negative emotion. Results depicting the frequency of positive and negative emotions found in question 1 of the pre and post survey. These emotions were coded through thematic analysis of question 1, which asked students to "write and/or draw what you think of when you hear the word science."

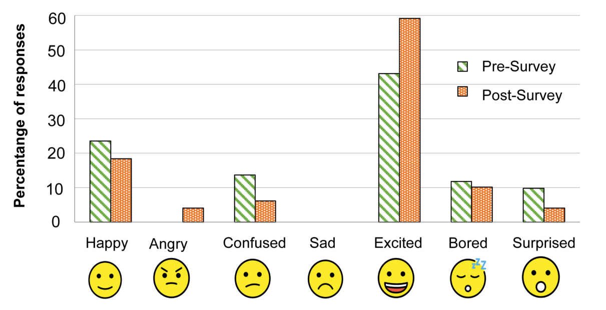

FIGURE 4 | Emoji selection pre to post survey. Results depict the percentage of frequency that each emoji was selected during pre and post surveys. Students were asked to select an emoji describing how science made them feel. Total number of occurrences of each emoji was divided by the total amount of emoji selections to determine percentage out of 100%. Pre survey had a total of 51 emojis selected, and post survey had 49. All emojis designed by OpenMoji.

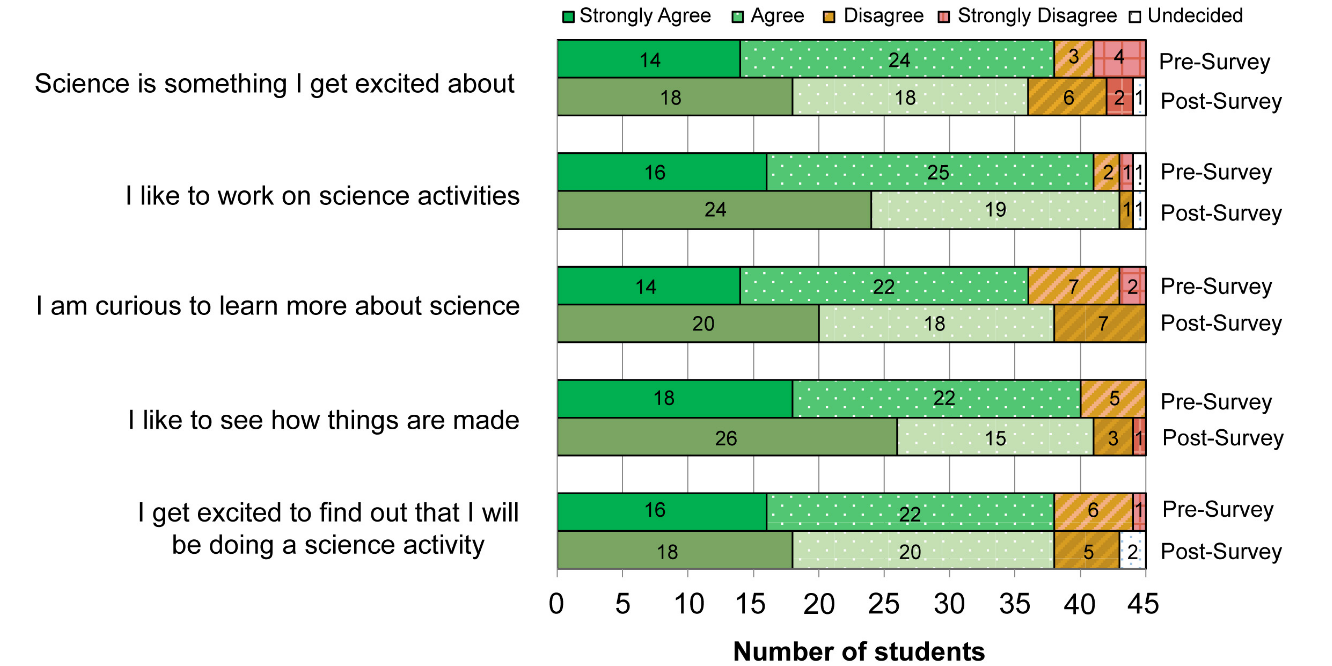

FIGURE 5 | Noyce enthusiasm for science statements. Results from the questions that evaluate enthusiasm toward science learning. Demonstrates the number of students that selected each answer. Pre and post survey answers are stacked directly, respectively, on top of each other for each question. Cronbach alpha 0.831 and 0.827 for pre and post survey, respectively.

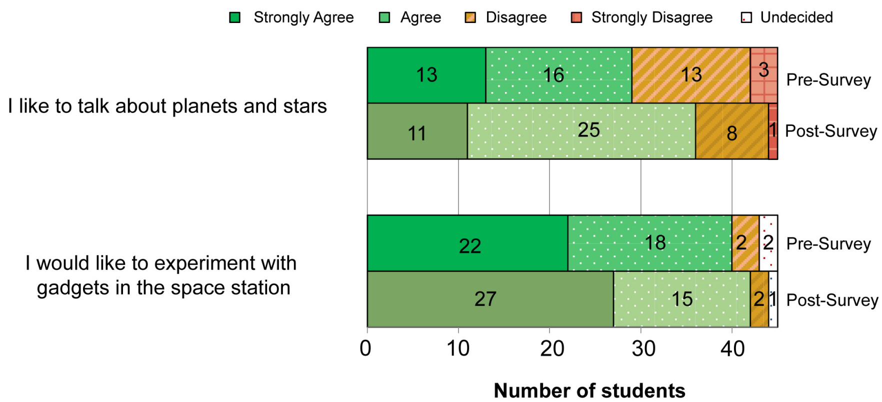

FIGURE 6 | Children's science curiosity scale statements. Results from the questions that assess student curiosity toward science learning from Harty and Beall (1984). Demonstrates number of students that selected each answer. Pre and post survey answers are stacked directly, respectively, on top of each other for each question.

The overall numerical mean scores for each set of questions representing different engagement and skills, decreased from pre to post survey. This indicates that participants chose answers more toward "strongly agree" and "agree" post survey as these were given lower numerical values of 1 and 2 for data analysis in comparison to "disagree" and "strongly disagree" (numerical values of 3 and 4, respectively). Paired t-tests were run for each variable, as found in **Table 5**, and demonstrated no significant differences between students' ratings from pre to post evaluation with a p-value at 0.05.

DISCUSSION

This study evaluated an in-school informal science outreach program in order to assess the impacts of such programming on student interest and engagement in science, and to explore the potential benefits of collaborations between formal and informal science institutions, specifically between schools and science centers.

In our evaluation, we found the logic model process valuable in clearly articulating the measurable student outcomes intended for the program. This step is a helpful starting point for

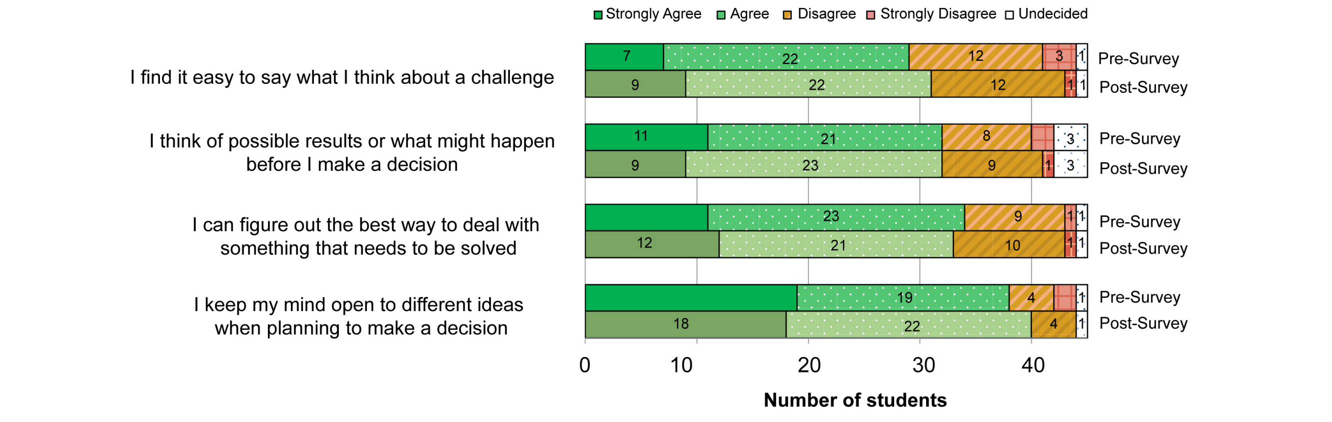

FIGURE 7 | Critical thinking statements. Results from the questions that evaluate critical thinking in science learning adapted from Perkins and Mincemoyer (2002). Demonstrates number of students that selected each answer. Pre and post survey answers are stacked directly, respectively, on top of each other for each question. Cronbach alpha 0.826 and 0.831 for pre and post survey, respectively.

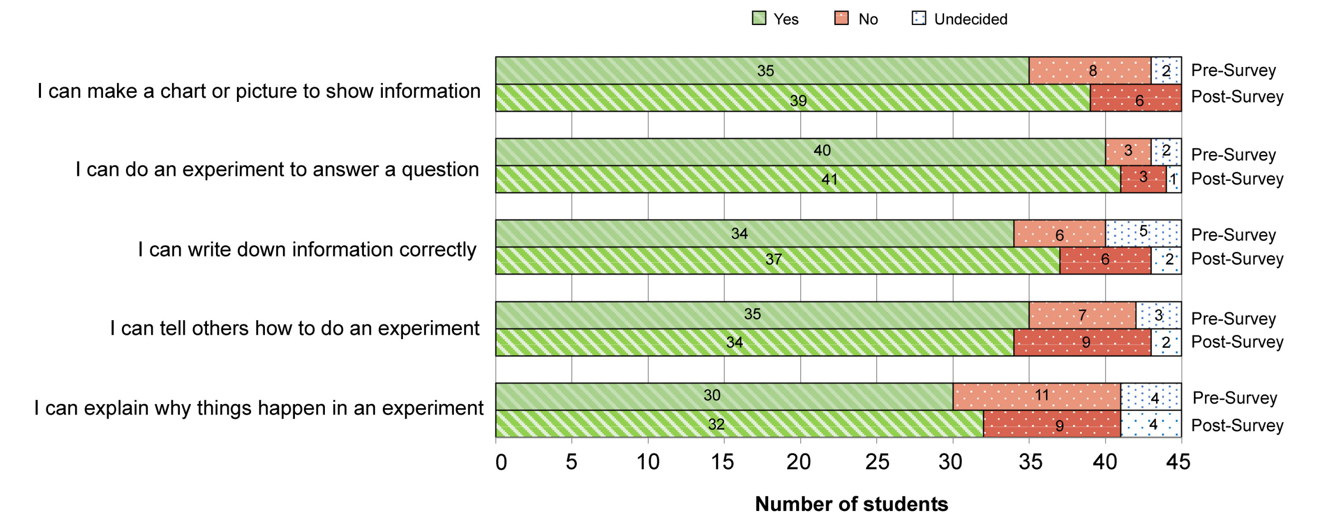

FIGURE 8 | Science process skills inventory statements. Results from the questions that assess experimentation adapted from Arnold and Bourdeau (2009). Demonstrates number of students that selected each answer. Pre and post survey answers are stacked directly, respectively, on top of each other for each question. Cronbach alpha 0.659 and 0.4 for pre and post survey, respectively.

program evaluation, assisting researchers in visualizing the resources being used on projects, the activities and participants in the programs, the intended outcomes, and how these aspects are inter-related. It is recommended that these logic models be created in partnership with schools to ensure the goals of both parties are being evaluated, thus supporting more valuable partnerships.

The logic model outlined the NSF Framework's (Friedman, 2008) impact of knowledge, engagement, and skills. These program outcomes were evaluated using pre and post surveys. Overall, our study found the following impacts subsequent to student participation in the "Mission to Mars" program:

- an increase in student knowledge on the program topic (space), aligning with school-related curriculum goals,
- an increase in student engagement, as more students reported more positive emotions, feelings of excitement, and sense of wonder toward science, and
- a small increase in the number of students reporting they have skills in experimentation and critical thinking skills following the program.

The findings of the program's impact on the NSF impact categories are described in more detail below.

Knowledge

Students mentioned the knowledge NSF impact category (Friedman, 2008) most frequently in the concept map question. The subject of "space" saw the greatest increase of occurrences after the "Mission to Mars" program. This program is based on space science and Mars exploration, which likely caused an

TABLE 5 | Paired *t*-tests for survey instrument results.

Survey intrument	Noyce enthusiasm for science	Science curiosity	Critical thinking	Science process skills inventory
T-test value	0.077	0.084	0.674	0.096

p-value at 0.05.

increase in student knowledge of space-related themes. This increase can be considered a successful benchmark in the program as increased knowledge of STEM related topics is a goal outlined in the logic model. This result also supports school curriculum goals on increasing student knowledge about space concepts.

Chemistry had the highest frequency of occurrences in both pre and post surveys which mirrors findings by studies that use the "Draw a Scientist Test" developed by Chambers (1983); children most commonly associate scientists as working in a lab, with chemicals, and other chemistry related equipment (Barman, 1999; Steinke et al., 2007). Diverse influencers, like television, books, or the internet, shape learners' views of science, or what a scientist is (Moje et al., 2004; Steinke et al., 2007), and students in the present study seemed to have similar preconceived notions of science, heavily focused on chemistry related themes as in these other studies. The frequency of the code "Bill Nye" supports this notion, as he is a well-known scientist figure that fits many stereotypes of a typical scientist found in the "Draw a Scientist Test." The increase in biology related codes could be attributed to external factors like learning biology related topics in class between pre and post surveys.

Students completed our surveys in a formal learning environment, and the physical environment where learning takes places can impact what a leaner expects to happen (Falk and Dierking, 2018a). It could be speculated that they referred to prior experiences of knowledge reporting in a classroom setting, like doing a test for example, when completing these surveys. This may have led to more knowledge-based answers vs. other outcomes, like skills or engagement, within the open-ended concept map question.

Engagement

Engagement was the second most frequently coded NSF Framework impact category (Friedman, 2008) and was separated into two sub-categories: positive and negative emotion. There was an increase of 29 occurrences (from 8 to 37) of positive emotions following exposure to the "Mission to Mars" program, which could be an indication that the program had a positive impact on how students feel about science. From pre to post survey, the overall number of emotional words increased from 18 to 43. This increase could indicate that students were emotionally impacted by the program as they were not prompted to report emotions or feelings in this question.

The results of the emoji scale showed that feelings of excitement toward science increased following the program, and was the greatest increase across the emoji scale. Excitement affects motivation, which is a key characteristic of informal learning, and in creating long-term intrinsic interests in science long after programs are complete (Bell et al., 2009). Positive emotions are a beneficial outcome as student engagement in school science continues to suffer, especially near adolescence (Corrigan et al., 2018). In-school outreach programs can bridge this gap by sparking excitement and motivation for STEM learning. The Science North Program "Mission to Mars" incorporates many hands-on learning opportunities with specialized tools, such as virtual reality and sensor building experiment. These interactive experiences are added to the program with the intent to increase a sense of wonder and engagement from students, which may have been a factor in the change in student engagement. Many studies have demonstrated that interactive science experiences support learning across the six strands from NSF and "seem to spark interest and maintain learners' engagement while also increasing knowledge and providing opportunities for reasoning" (Fenichel and Schweingruber, 2010). Recent studies investigating the use of virtual reality in science education suggest that its immersive aspect can increase motivation and engagement for learning science (Yamada-Rice et al., 2017; Fauville et al., 2020; Zhao, 2020).

Using the Noyce Enthusiasm Scale for Science statements (Mielke et al., 2002), the majority of students reported having a sense of wonder or enthusiasm toward science even before participating in the "Mission to Mars" program. This is likely from previous science learning, personal interest, or everyday experiences (Hein, 2009). Our results also suggest that students who initially reported a moderate sense of wonder toward science reported a higher sense of wonder as a result of their experience with the program. From pre to post program, nine students went from reporting feeling little to no enthusiasm toward the statement "I like to talk about planets and stars," to feeling enthusiasm post-program. These emotional changes are important for brain functions like attention, reasoning, memory, and learning (Tyng et al., 2017), and positive emotions, like excitement and sense of wonder, can lead to further curiosity and long-term interest in science (Hein, 2009). The increase in positive emotions toward science may play a part in the cognitive abilities of students learning science concepts, and may spark long-term interest—a common goal across informal science programs. The Cronbach alpha results for the Noyce Enthusiasm for Science statements demonstrate a good internal consistency (0.83 and 0.83 for pre and post survey, respectively).

It is important to consider that reported emotions and affective outcomes may be influenced by a variety of factors, such as socioeconomic aspects, family life, or physiological needs like hunger (Tyng et al., 2017), and students may have had difficulties recognizing specific emotions they were feeling. For example, if a student was frustrated during the program due to teamwork issues or program difficulties, "angry" may have been selected in the post survey as "frustrated" was not an option. This could explain the two students who chose "angry" in the post survey. Similarly, the word "shocked" can be associated with surprise, and it is found in the negative opinion lexicon in the NRC Word-Emotion Association Lexicon (Mohammad and Turney, 2013), suggesting that shock or surprise might be a negative emotion to some students, possibly explaining why this emotion appeared less frequently in the post survey.

Skills

Skills had the second lower number of occurrences ("other" being the most frequent) of the NSF Framework (Friedman, 2008) impact categories we assessed with our survey. Friedman (2008) argues that although there is a difference between doing and knowing, learners may not be able to acknowledge or describe the skill they possess, and this may explain the few responses received for this outcome.

Experimentation

The number of students associating the skill of experimentation with science increased post-program, and experimentation was coded most frequently in the qualitative data because students wrote the word "experiment" on their concept maps. This increase post-program may not mean students felt their ability to conduct an experiment increased, but could suggest greater awareness that experimentation is part of the scientific process.

The ability to explain why things happen in an experiment was the skill least reported from the Science Process Skills Inventory (Arnold and Bourdeau, 2009) both pre and post. While more students were able to report being able to do an experiment to answer a question, fewer students reported being able to explain the "why" of an experiment. Similarly, Knaggs and Schneider (2012) determined that process understanding proceeds concept understanding, and in their study, students reported they had the skills required to complete experiments, but lacked the scientific reasoning skills to explain the phenomena that were occurring. They inferred that this higher-level thinking in science is a skill that takes time to develop, and so the single, short-term program evaluated in the present study may not have given the students enough exposure to these skills for there to be a noticeable change. A long-term study with frequent programs offered by in-school science outreach organizations would be needed to assess potential change in students' reported science-based skills.

Within the "Mission to Mars" program, student experimentation skills were tested through building and launching sensor protection devices, which could have caused the increase in experimentation codes within the concept map. While students may have understood that they needed to construct a device that protects their sensor during launch, perhaps there was a lack of information within the program regarding why this process was being done, and the larger implications (i.e., a more protected sensor means the rover can successfully land on Mars and deliver). This could explain for the lower number of students self-reporting that they could explain why things happen in an experiment.

Critical Thinking

The majority of students self-reported that they were able to do several critical thinking actions pre-program, and the frequency of students reporting that they could do these actions post-program showed little change. Within the program, students critical thinking skills were challenged through spending a budget on materials for their sensory protection device, and through planning, designing, and testing their device. Students were challenged to alter the device so that it would cause the lowest impact (gravitational force), thus protecting the sensor inside. While the program intended to see a change in student critical thinking skills, according to Piaget's theory of cognitive development, children develop abstract reasoning skills between the ages of 11 and 16, including the development of critical thinking skills (Piaget and Inhelder, 1972). Our student participants were in Grade 5 and 6 (10 and 11 years of age), suggesting that they may have just started developing these critical thinking abilities. While these survey instruments were intended for the age range of this study, further research could utilize a similar method with older students to determine if there is a greater change in critical thinking and experimentation understanding. The Cronbach alpha results for the Science Process Skills Inventory statements demonstrate poor internal consistency (0.66 and 0.40 for pre and post survey, respectively). This result demonstrates that these statements may not be consistent with one another in measuring critical thinking and thus these statements may not effectively evaluate critical thinking.

Paired t-tests were run for each survey instrument variable and demonstrated no significant differences between students' ratings from pre to post evaluation with a p-value at 0.05. We can speculate that the lack of significant difference has been impacted by a small n as this can diminish power when comparing these types of data sets. This, however, does not mean the program did not have impact on the students, and when we consider the goals of informal science programs like this, each piece of science communication is meant to add impact over exposure, over time. The results show an upward trend of students self-reported science awareness, positive emotional response, and enthusiasm and curiosity toward science. From this, we can conclude that more research needs to be done in depth to strengthen the reliability and validity of these findings.

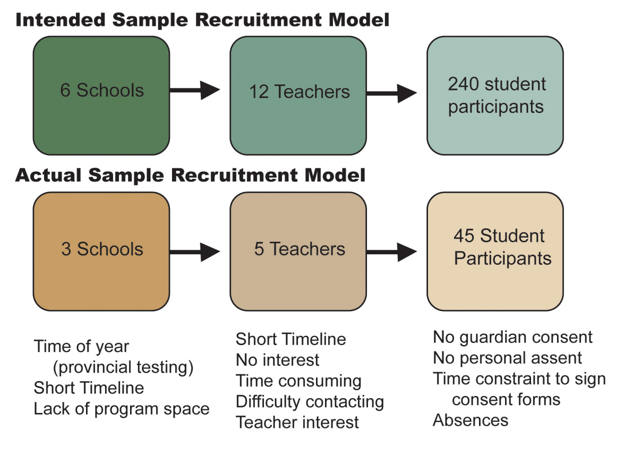

FIGURE 9 | Sample attrition model. Model demonstrating the loss of potential participants at each step of the recruitment process. The top diagram models the optimum flow of recruitment, ending with 240 student participants, while the bottom demonstrates the actual flow of recruitment along with reasons for potential participant attrition below each step.

Implications

Teachers face barriers in implementing inquiry-based science into classrooms, however, incorporating informal science learning through in-school outreach may address time-restraints, funding, and lack of technical skill (Davis, 2003; Schwarz and Stolow, 2006; Stocklmayer et al., 2010). These partnerships echo the recent push for an "ecosystem-based" approach to science education, allowing learners access to a network of intersecting science learning opportunities, creating a rich science learning experience (Falk and Dierking, 2018b). Informal science organizations' partnerships with formal education institutions could especially benefit under-served and rural schools as they may encounter more barriers and have even less resources to incorporate inquiry-based learning into classrooms (Bell et al., 2009; Bevan et al., 2010).

Evaluating the impacts of in-school science outreach demonstrates the potential benefits and outcomes of this type of programming on students' knowledge, engagement, and skills in science, further solidifying the role that these science center-based in-school learning opportunities can have.

Limitations

Sample Size

By evaluating a single program within a single school board, we recognize that the results cannot be used to make inferences about entire populations of students participating in Science North programs, and without a control group, it is difficult to determine other factors that may have influenced the changes we documented with this sample. We saw a large reduction in sample size (**Figure 9**) from an expected 240 students to 45 students mostly due to consent requirements.

Concept Map Method

Student concept map drawings were interpreted as icons, or what they appeared to represent physically at surface level, and were translated into single words or phrases. Interpreting a drawing strictly on physical resemblance can lose the complex, deeper meaning that could have been intended. Türkcan (2013) assessed drawings by children and found that even among similar drawings, students had different mental models of what these images meant. This deeper level assessment of student drawings, as well as the actual organization and layout of the concept maps, would be an interesting analysis for future studies to gain a deeper understanding the impact of in-school outreach programs.

Use of Emoji Scale

Emoji scale results demonstrated that students chose multiple emojis, indicating feelings of more than one emotion toward science. In addition, the emoji representing sadness was not chosen in either the pre or post survey, indicating that this may not be an emotion commonly felt toward science. Future use of emoji scales in studies with children should take these findings into consideration when designing such scales.

Interval of Time Between Pre- and Post-surveys

A 7-day interval between the pre-survey and the in-school outreach program, followed by another 7-day interval before the post-survey allowed other variables to potentially affect students' self-reported outcomes, including additional science lessons and discussions about the Science North program. While these other learning opportunities and events support the notion of a science learning eco-system, it creates difficulties in determining the direct outcomes of specific program interventions.

Additional Methods of Data Collection

Other methods of data collection such as interviews and focus groups, although not feasible during this study due to time constraints, are certainly desirable for a study examining what student experiences lead to changes in their experimentation skills, critical thinking skills, and their sense of wonder. Future investigations could consider such methods of data collection to gain a deeper understanding of the students' perspectives following in-school outreach programs.

CONCLUSION

In-school science outreach is a unique form of informal science education, done in collaboration with formal institutions, that can positively impact students' science knowledge, engagement, and skills. Research investigating the outcomes of these programs can further support the inclusion of science center-led, in-school outreach science programs in science classrooms.

Our study evaluated an in-school science outreach program through a case study of the Science North program "Mission to Mars." The use of a logic model to establish program goals and outcomes was valuable in this evaluation and is recommended for other institutions. The logic model we created can be used as a template for other organizations doing similar in-school informal science outreach. It is recommended that these be created in partnership with schools to create mutually beneficial programs with student outcomes that align with goals of all organizations involved. We used the logic model to determine student changes in outcomes that align with the NSF Framework (Friedman, 2008) impact categories of knowledge, skills, and engagement, which are also related to Science North strategic goals of increasing: (1) experimentation, (2) critical thinking, and (3) sense of wonder.

Our pre and post surveys demonstrated increased student knowledge on the program topic, aligning with school-related curriculum goals. Students self-reported higher engagement levels through an increase in positive emotions and feelings of excitement toward science following exposure to the program. The Science North outcome of sense of wonder, aligning with our evaluation of student curiosity for science, increased following post-program, and sense of wonder toward space-related science also increased. Increases in students' positive emotion toward science could, in the short-term, increase student motivation toward science, leading to long-lasting interests in science. Finally, only a small number of students reported an increase in skills such as experimentation and critical thinking post-program. These skills take time to develop, and it can be argued that the single, short-term program evaluated in this study did not provide the students with enough exposure for them to self-report a change, and at ages 10–11, they may be in the initial stages of gaining, and recognizing these important skills in relation to science.

Integrating inquiry-based methods of teaching into classrooms may be challenging for some schools, but partnering with an informal science institution, like a science center, can bring engaging science learning opportunities for students. Evaluating the impacts of in-school science outreach helps demonstrate measurable outcomes on students' science learning and engagement with science topics, while providing empirical evidence of the potential benefits of these science center-led programs to formal science education.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Laurentian University Research Ethics Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

KR conducted the study, drafted the manuscript with guidance, and edited contributions from CB (research supervisor), and KP (co-supervisor). All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.675306/full#supplementary-material

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