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PROMOTING DATA SCIENCE IN SCHOOLS: FACILITATING THE USE OF OPEN DATA AND SENSORS IN SECONDARY EDUCATION

BY
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Promoting data science in schools: Facilitating the use of open data and sensors in secondary education

Ph.D. Dissertation

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Abstract

This dissertation explores how open data and sensor data can help younger students (aged 11–15 years, in fifth through ninth grade) learn digital and data skills and how to develop an educational design for open data platform to facilitate secondary school education. The research is divided into two parts. The first part examines the use of open data and sensor data in education from the perspective of teachers, while the second investigates how the digital divide in education can be bridged by utilizing educationally relevant open data platforms and sensors.

An enormous amount of data is generated every day through the use of digital technology. As a result of digitalization, open data — data that is publicly available for anyone to use, reuse, and redistribute — has been used and studied to foster economic development, facilitate transparent governance, and empower people around the world. The digital and data shift can potentially be used to transform conventional teaching methods and to find new strategies and practices for teaching the skills that are necessary to survive and thrive in the modern era. Data literacy is becoming an essential skill for teachers and students to meet the needs of the twenty-first century.

This dissertation investigates how open data can be used as a source of freely available educational material for young students (aged 11–15 years). In the first part of the dissertation, qualitative and quantitative research methods are used to investigate teachers' perspectives on open data literacy and the potential effects on students, as well as how open data can be used to improve digital and data literacy skills among secondary school students. Various challenges are identified that currently hinder the use of educational open data sets in school education.

In the second part of the dissertation, an "enterprise architecture-oriented requirements engineering" (EAORE) approach is proposed to identify teachers' requirements and needs for using open data as an educational resource in Danish public schools. Using this approach, a design for an open data interface (ODI) was developed to help schools integrate open data into their lesson plans. The usability of the ODI is evaluated with school teachers and students through usability tests in various scenarios.

The use of sensor technology, which also plays an important role in data-collection activities, provides students with hands-on experience in how data is collected and used to make decisions. We propose a set of criteria for assessing the degree to which sensors are compatible with a given curriculum. The criteria were developed particularly for secondary school students in grades 5 through 9 and were designed for use by students and teachers in their daily teaching. Requirements models for curricula-compatible sensor classes that meet the criteria were developed using requirements-engineering techniques.

The findings indicate that the use of open data and sensor data in education has the potential to advance the digital and data skills of future generations, as well as help them understand their surroundings by incorporating real data sets into their subjects. The findings also show that the ODI assists educators in utilizing open educational data sets in schools and bridging the digital divide in education by integrating educational open data sets into school subjects. Furthermore, sensor integration in schools can enhance students' digital and data skills, and the use of requirements models for curricula-compatible sensors can assist in the development or transformation of existing sensors into curricula-compatible sensors.

Resumé

Denne afhandling undersøger hvordan åbne data og sensordata kan assistere femte til niende klasses elever i alderen 11-15 år med indlæring af digitale og databaserede kompetencer, samt hvordan en uddannelsesplatform for åbne data, der kan understøtte gymnasiale uddannelser, konstrueres. Første del af afhandlingen analyserer brug af åbne data og sensordata i uddannelsesregi fra underviserens synsvinkel. Anden del undersøger hvordan den digitale kløft har betydning for undervisning, og hvordan den kan overkommes ved hjælp af uddannelsesmæssigt relevante åbne data platforme og sensorer.

Hver dag genereres enorme mængder af data ved hjælpe af digitale teknologier. Som konsekvens af digitaliseringen, er åbne data – data der er offentligt tilgængelige og frit kan bruges, genbruges og distribueres – blevet benyttet og studeret med henblik på at fremme økonomisk udvikling, facilitere åben og gennemsigtig forvaltning, samt styrke mennesker rundt om i verden. Den digitale omstilling har potentiale til at reformere konventionelle undervisningsmetoder, og udvikle nye strategier og metodik for indlæring af den teknologiske viden, der er så nødvendig for at overleve og trives i den moderne æra. Digitale færdigheder er blevet essentielle for både undervisere og studerende, for at imødekomme de basale behov i det 21. århundrede.

Afhandlingen undersøger hvordan åbne data kan benyttes som en frit tilgængelig ressource for undervisningsmateriale for elever i 11-15 årsalderen. Første del af afhandlingen benytter kvalitative og kvantitative forskningsmetoder til at undersøge effekten af manglende datafærdigheder hos elever fra en undervisers perspektiv, samt hvordan åbne data kan benyttes til at fremme digitale færdigheder hos elever på gymnasiale uddannelser. Adskillige nuværende forhindringer for brugen af åbne datasæt for udnyttelse i undervisningsregi identificeres.

Anden del af afhandlingen præsenterer en "enterprise architecture oriented requirements engineering" (EAORE) metodik, der benyttes til identifikation af underviseres krav og behov ved brug af åbne data som læringsressource i den danske folkeskole. Metodikken anvendes til at udvikle et design for et "open data interface" (ODI), for at facilitere integration af åbne data i deres undervisningsplaner. Anvendeligheden af ODI'et bliver evalueret af

skolelærere og elever via forskellige brugervenlighedstest.

Anvendelsen af sensorteknologi, der har en dominerende rolle for dataindsamling, giver de studerende en praktisk erfaring i hvordan data frembringes, indsamles og udnyttes til beslutningsstøtte. Vi præsenterer et sæt kriterier for vurdering af graden af kapabilitet for sensorer for et givent pensum. Kriterierne er specifikt tiltænkt for elever i 5. til 9. klasse, og blev designet til at blive benyttet af studerende og undervisere i deres daglige undervisning. Kravs modeller for pensum-kompatible sensorer der opfylder kriterierne blev udviklet via ingeniør-kravspecifikationsteknikker.

Resultaterne indikerer at benyttelse af åbne data og sensordata i undervisningsregi har potentiale til at forbedre digitale kompetencer og datakompetencer for fremtidens generationer, samt hjælpe dem med at forstå deres omgivelser via integration af håndgribelige datasæt i undervisningen. Yderligere viser resultaterne at ODI'et assisterer undervisere i brugen af åbne undervisningsdatasæt i skoler og overvinder den digitale kløft i undervisningsregi via integration af åbne undervisningsdatasæt i undervisningsemner. Slutteligt kan integration af sensorer på skoler bidrage til at udvikle studerendes digitale kompetencer og datakompetencer, og anvendelse af kravs modeller for pensum-kompatible sensorer kan understøtte udviklingen og transformation af eksisterende sensorer til pensum-kompatible sensorer.

Preface

This PhD dissertation is organized as a collection of papers and is divided into three parts. **Part I** introduces the dissertation and provides an overview of relevant background material, which leads to a problem formulation, followed by a brief description of how each paper contributes to a solution. **Part II** consists of a collection of papers, each of which may be viewed as an independent contribution to addressing the overall problem while having some internal relationships. **Part II**, the main body of the dissertation, includes three peer-reviewed conference papers and three journal papers. The individual papers/chapters are as follows:

Chapter 4
Paper 1: Open data visualization in Danish schools: A case study

Chapter 5
Paper 2: Bringing open data into Danish schools and its potential impact on school pupils

Chapter 6
Paper 3: Enterprise architecture oriented requirements engineering for the design of a school friendly open data web interface

Chapter 7
Paper 4: Open data interface (ODI) for secondary school education

Chapter 8
Paper 5: Towards using sensors as data sources in teaching: Requirements for school curricula-compatible sensors

Chapter 9
Paper 6: Digital innovation in education: Perspectives, opportunities, and challenges of educational open data and sensor data

Chapters 4 and 5 (papers 1 and 2) contribute to the humanistic aspect of open data and sensor data by examining how the use of open and sensor data can facilitate education. The first paper elaborates on the perspectives of teachers regarding open data usage in schools. The main contributions of this paper are to investigate how the use of open data visualizations can facilitate education at the school level and to provide an analysis of various tools that can be used to visualize open data as part of school subjects. The second paper contributes by generalizing the use of open data as an educational resource concept by analyzing and categorizing open data general themes into educational themes and then testing them with students and teachers. The study identifies existing data skills and competencies among students, examines the impact of the use of open data on school students, and investigates the challenges in integrating open data into school education.

Chapter 6 (paper 3) addresses teachers' need for open data interface. The main contributions include a literature review of open data use in education, a proposed approach to identify requirements models for the use of open data in schools, and the design of an open data interface (ODI) to facilitate teachers and students.

Chapter 7 (paper 4) evaluates the usability of the ODI in school education. Chapter 8 (paper 5) discusses the opportunities and challenges of using sensors in school education and contributes to the development of criteria and requirement models for curricula-compatible sensors. Chapter 9 (paper 6) discusses the future opportunities and challenges of open and sensor data use in education.

My contribution to each paper is summarized in the co-author statements, which have been signed by all coauthors, approved by the Technical Doctoral School of IT and Design, and made available to the assessment committee prior to assessment (see colophon for committee members).

Part III discusses the papers' findings, illustrates future work, and concludes the dissertation.

Each paper's chapter heading page states the planned publication venue and is followed by a copyright notice pertaining to the paper, which applies until the next chapter or part heading. The paper's layout and formatting have been revised, and obvious typos have been corrected. The dissertation's references are compiled at the end.

List of publications

The following is a list of my peer-reviewed publications. Six publications are published during the PhD project while one is under publication process at the time of submission.

One of the published manuscripts (*) is extended to a journal paper (paper 3) and not included in this dissertation. Another manuscript (**) is under review and not included in this thesis as I am not the first author of the paper and the research work is not directly related to my PhD work.

Papers included in the thesis

1. M. Saddiqa; B. Larsen; R. Magnussen; L. L. Rasmussen; J. M. Pedersen, " Open data visualization in Danish schools: A case study," *International Conferences in Central Europe on Computer Graphics, Visualization and Computer Vision: Proceedings – Part II. red. / Vaclav Skala. Vaclav Skala - UNION Agency*, pp. 17–26, 2019.

2. M. Saddiqa; B. Larsen; R. Magnussen; L. L. Rasmussen; J. M. Pedersen, "Bringing open data into Danish schools and its potential impact on school pupils," *Proceedings of the 15th International Symposium on Open Collaboration (OpenSym '19)* , pp. 1–9, 2019.

3. M. Saddiqa; M. Kirikova; R. Magnussen; B. Larsen; J. M. Pedersen, "Enterprise architecture oriented requirements engineering for the design of a school friendly open data web interface," *Complex Systems Informatics and Modeling Quarterly*, issue. 21, pp. 1–20, 2019.

4. M. Saddiqa; R. Magnussen; B. Larsen; J. M. Pedersen, "Open data interface (ODI) for secondary school education," *Computer & Education, Elsevier*, 104294, 2021.

5. M. Saddiqa; M. Kirikova; R. Magnussen; B. Larsen; J. M. Pedersen, "Towards using sensors as data sources in teaching: Requirements for

school curricula-compatible sensors,"*Complex Systems Informatics and Modeling Quarterly*, issue. 26, pp. 78–93, 2021.

6. M. Saddiqa; R. Magnussen; B. Larsen; J. M. Pedersen, "Digital innovation in education: Perspectives, opportunities, and challenges of educational open data and sensor data," *In 12th Workshop on Information Logistics and Digital Transformation*, under publication process, 2021.

Papers not included in the thesis

* M. Saddiqa; M. Kirikova; R. Magnussen; B. Larsen; J. M. Pedersen, "Enterprise architecture oriented requirements engineering for open data usage in schools," *Proceedings of 18th International Conference on Perspectives in Business Informatics Research, Springer. Lecture Notes in Business Information Processing*, volume. 365, pp. 135–147, 2019.

** B. Loenen Van, A. Zuiderwijk, G. Vancau-wenberghe, J. F. Lopez-Pellicer, I. Mulder, C. Alexopoulos, R. Magnussen, M. Saddiqa, M. Du-long de Rosnay, J. Crompvoets, A. Polini, and C. C. Flores, "Towards value-creating and sustainable open data ecosystems: A comparative case study and a research agenda,"*JeDEM - eJournal of eDemocracy and Open Government*, under review, 2021.

This thesis has been submitted for assessment in partial fulfillment of the PhD degree. The thesis is based on the scientific publications listed above, which have either been submitted or have been published. Parts of the papers are used directly or indirectly in the thesis's extended summary. Co-author statements have been made available to the assessment committee and are also available at the faculty. Because copyright may not be ensured, the thesis is not acceptable for open publication in its current form, but only for limited and closed distribution.

Acknowledgments

This dissertation, as the greatest and most challenging accomplishment of my career so far, would not have been possible without the contributions of many people, and I would like to thank them here. I would first like to thank and express my gratitude to my advisor, Prof. Jens Myrup Pedersen, for his unwavering support of my PhD research, for his motivation and encouragement, and for his ability to see the research from various perspectives.

Rikke Magnussen and Birger Larsen have excelled as co-supervisors: they have guided on deep humanistic and technical aspects, offered insightful comments, and initiated many fruitful discussions, all while maintaining the "big picture" to an impressive degree. I am extremely grateful to both of you.

I would like to thank the Computer Science Department at Riga Technical University for providing me with the opportunity to work in the requirement-engineering domain. Marite Kirikova has been extremely helpful to me in the realm of requirements engineering, both during my stay at Riga Technical University and during virtual meetings, by providing helpful guidance, advice, and discussions. Thank you.

I would like to thank Preben Mogensen, section head of the Wireless Communication Networks section, and Reza Tadayoni, section head of Communication, Media, and Information Technologies, both at the Department of Electronic Systems at Aalborg University, for their assistance throughout the project. Dorthe Sparre, section secretary of the Wireless Communication Networks section, and Anette Byøse, section secretary of the Communication, Media, and Information Technologies section, have been invaluable in assisting with many practical issues and formalities. Thank you both for being there.

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Mubashrah Saddiqa
Aalborg University, September 14, 2021

Contents

Part I

Introduction

Chapter 1

Introduction

Evolving data sources have influenced how scientific data is used to affect policy, public perceptions, business strategies, and research efficiency [1, 2]. Data visualization, open data, sensor data, and big data are all significant advances in digitalization. In recent years, governments, administrations, and individuals have focused on these data types and their applications.

Open data consists of openly licensed data sets that can be accessed, used, rebuilt, and shared by anyone free of charge [3]. Data has become more accessible over the last decade as a result of various open data initiatives. These initiatives are intended to achieve objectives such as openness, innovation, citizen participation, improved public services and governance, and the creation of both social and economic value [4, 5].

Despite the enormous potential of open data, many challenges hinder the realization of open data's potential, such as mismatches between openly shared data sets and those that the public demands [6], lack of cooperation by public agencies [7] or insufficient care when providing data sets [8].
Previous research has also pointed to the need for open data ecosystems that focus not just on accessing the data but also on the broader context of open data use [9]. Osorio-Sanabria et al. [10] identified five components that an open data ecosystem must have to realize the associated benefits: a political/legal framework, actors, technological infrastructure, data, and standards or tools to facilitate data interoperability. Different case studies of open data systems in different countries have also been discussed [11] including open geographical, research, agriculture, education, media, and legal data systems.

In recent years, technological innovation, digitalization, and the availability of open data have also influenced educational research and practices in schools. Digital and data literacy is becoming increasingly important as a skill set that prepares individuals to live, learn, and work in a digital society [12]. Open data can be used as an educational resource to help students develop cross-disciplinary skills [13]. The reform of learning methods and the incorporation of digital and data-related content into the education system have both become necessary to provide students with the skills they need to meet future demands [14,15].

The use of open data has various educational advantages. Open data can potentially assist young students in learning how to collect, manage, and analyze data. In addition to data and digital skills, other capabilities associated with the use of open data as an educational resource include statistical abilities, critical thinking, and teamwork [16].

Although open data has enormous potential, its actual use in education remains limited [17]. Many teachers are unaware of the benefits of using open data in the classroom and may encounter difficulties if attempting to do so [17,18] - such as how to incorporate the use of these data sets into the instructional design to improve students' digital and data skills, as well as how to find appropriate data sets. One major barrier to incorporating open data into school education is that the concept of data is often too abstract for students to grasp [18]. They need hands-on experience to understand the data concept and its use in real life [19]. Sensors can play an important role in this regard. Sensor technology is widely used in a variety of educational activities [20] and can be an excellent way for young children to grasp the concept of data [21].

The limited research on the use of open data in school education indicates a gap due to the lack of awareness among teachers about educational aspects of open data and a dearth of tools and technologies to provide direct access to educationally relevant open data sets. To bridge this gap, open data platforms are needed that will provide teachers and students with access to data sets that are relevant and useful in an educational context.

Such easily accessible data sets, for example in the form of visualizations and graphs, can facilitate teachers in connecting their subjects with the real world and can allow teachers to spend more time planning learning activities rather than finding and filtering appropriate data sets [22]. Students need to have hands-on experience with data-related activities to become acquainted with the concept of data. This scenario can be accomplished by incorporating sensors into the classroom that will allow students to collect data in a real-world setting. This strategy will also help students understand how data is generated and will show them how to analyze data to make decisions or solve problems.

This research is part of the Community Drive project[1], a technological and humanistic research and development project centered on knowledge co-production, education, and learning [23]. The main contribution of this thesis

[1] `https://www.communitydrive.aau.dk/`

is to identify the upsides of using open data and sensors in education - as well as the challenges of using open data and sensors in the classroom - and to propose solutions in order to reap the benefits from the use of educational relevant open data and sensor data.

Chapter 2

Background

This chapter outlines the evolution of the use of open data and sensor data in education. A brief overview of the educational aspects of open data and sensor data begins the chapter, followed by a description of the state of the art for open data platforms and sensors for school education.

1 Educational aspects of open data

Education is an integral component of ensuring that future generations will have the skills they need and can act as a catalyst to empower students with digital and data abilities so they can face future challenges. The availability of more data opens up a broad range of data applications. For example, the open data concept aims to improve the efficiency and flexibility of instructional resources by leveraging data and connected technology [24]. Open data may also be used to improve, organize, and make educational institutions' learning and administrative processes more transparent [25]. For example, the Open Data Project[1] facilitates schools in learning from one another by sharing and comparing administrative and management data collected for the benefit of students. Finally, open data may be considered the foundation upon which the educational process is formulated as discussed by Henty in [18].

Previous studies [13, 26] have identified several uses for the introduction of open data in schools, such as open data as a material for learning. Similarly, Watson in [27] investigated statistical literacy from the viewpoint of schoolchildren, as well as how the use of open data can enhance students' learning experiences. Open data can enable students to engage in cross-curricular activities, such as linking mathematics (formulating means, aver-

[1] `https://opendataproject.org.uk/`

ages, differences, etc.) with other subjects such as science, social science, and geography. Such data can also assist students in conceptualizing real-world problems through visualization and graphical presentations. Atenas et al. [28] have examined how open data can be used as an educational resource and have examined the associated outcomes of integrating open data into classrooms activities. The authors in [29] focused on how open data usage can become the object of learning and in which areas such data is applicable. The authors also discussed different open data initiatives[2] within the educational field.

Simply making open data available is not enough to use it as an instructional resource, however; teachers and the educational community must also be aware of open data's educational potential [30], and didactic models and guidelines for integrating open data use into education are also required. The achievement of open data skills also depends on the pedagogical use (e.g., inquiry-based learning [31]) of these data sets in teaching activities. Diego et al. [32] have analyzed the state of the art in open data research using descriptive, conceptual, and co-word analyses in different domains of data; the authors identified health, engineering, public administration, education, and management as the main knowledge areas. Many countries have also taken measures to integrate open data into their schools and have initiated open data projects, including the United Kingdom[3], Norway[4], and Spain[5], among others.

Even though open data has the potential to be used as an educational resource and as a raw material to help students understand the concept of data - for example, by involving them in city transition projects or to better understand their surroundings by utilizing population, pollution, or traffic data sets, several barriers exist in using these data sets as an educational resource. Such as disinclination due to a lack of knowledge about open data opportunities, access to relevant data sets, data skills, and so on. For instance, previous studies [13, 17] have identified a lack of awareness of open data potential in education as one of the main barriers to open data integration into school education. Other researchers [18, 33, 34] have also listed barriers that may influence the use of open data in education, including a scarcity of technical expertise, teachers' lack of understanding of open data and a general lack of teacher training, and difficulties in using available data (because most open data sets come from public sector management and scientific research institutions). In some cases, students and teachers do not have the skills or resources to take advantage of these data sets.

The use of open data has the potential to change many industries, in-

[2] http://opendataschool.ru/

[3] https://dataschools.education/

[4] https://site.uit.no/opendatainteaching/

[5] https://opendata-ajuntament.barcelona.cat/es/repte-barcelona-dades-obertes

cluding education. Today's education field, starting from elementary and secondary school education, must be enriched with new learning methodologies and should integrate openly available educational sources and real-world data sets to enhance the teaching and learning process. The limited research on open data use in education has also shown a positive influence on learning environments [18, 29, 35].

2 Educational aspects of sensor data

Students can benefit from working with data when it is connected to meaningful inquiry and when they have opportunities to participate in the construction, representation, analysis, and use of data [36]. Sensors can play an important role in providing hands-on experience with data collection activities to help students understand the concept of data. Exploratory learning is thought to be a powerful way of introducing children to computer science concepts. The authors in [37] have discussed how exploratory learning using sensors supports STEM (science, technology, engineering, and mathematics) skills around the world.

Since the beginning of the twenty-first century, the use of sensors has often been regarded as a powerful strategy in science and mathematics education that has contributed to improved learning outcomes [38] and teachers' positive experiences in science teaching [39]. Sensors are frequently used as an extension of the human senses in everyday life [40]. They are embedded in mobile devices, allowing for pervasive, implicit, and explicit learning and health activities [41].

Researchers have also undertaken various studies of integrating sensors and their advantages in educational activities within secondary and primary schools [42]. For instance, Alexandra et al. [43] reported on a teaching and learning experience to empower schoolchildren through the promotion of environmental health in schools through the use of sound sensors. Such sensors, along with a free app, were used to elevate student awareness about noise and its effects. Children learned how to use sound sensors to perceive sound in practical ways, such as by producing recordings, analyzing and signifying the recordings, and drawing conclusions. The authors in [44] have discussed the results of a study with first-grade students. The students collected meteorological data throughout the school year and created graphs to depict their findings. The research results revealed the students' keen interest in data-collection activities as well as details about how the first-graders interacted with graphs, maps, and data logging instruments.

Many researchers, e.g., [45, 46] have also noted that students lose interest in and cease to actively participate in science and mathematics subjects without exploratory activities, although these subjects become interesting for primary and secondary school students when using sensors and technology with inquiry-based learning [42, 47]. The authors in [48] researched to evaluate the effect of various sensors in school subjects. The authors also looked into whether such practices had an impact on teachers' teaching processes and attitudes, as well as students' learning behaviors, involvement, and inspiration. Data loggers and sensors of temperature, pH, force, and distance were used in the study. Almost 200 students (aged 12 to 17), from six schools in Germany, France, Turkey, and the United Kingdom, as well as 30 teachers from eight schools, provided feedback on the use of data loggers in lessons and their influence on their motivation and learning. The findings indicated that using data loggers boosted students' grasp of information and communication technologies (ICT) in general and helped them critically analyze the use of data and scientific techniques in particular, thus making it easier for the students to connect chemistry, physics, and biology to their everyday lives. The usage of sensors in the classroom also strengthened relationships and collaboration among the students.

The goal of the various projects under the micro: bit Educational Foundation [49] is to motivate students to participate in digital learning activities to acquire future essential skills. The projects' goal is to use a small programmable and embeddable computer-designed device to fill the gap between abstract data concepts and practical experiences at the primary and secondary education levels.

While much research has shown how interacting with sensors can promote data reflection, questions persist about developing materials and curricula that could promote a variety of digital and data skills among students, such as how data-collection activities should be integrated into school curricula, what design of curricula-compatible sensors should entail, and how to engage young students with the sensors.

3 Existing research

3.1 Open data platforms for education

Various educationally relevant data sets are made available by governments through open data portals under themes such as transportation, environment, culture, population, and so on. The EU Open Data Portal[6] provides access not only to various open data sets but also to published use cases of these data sets in different areas such as education, science, and culture. Finding educationally relevant information, however, still necessitates extra effort from teachers in the school environment.

[6] `https://data.europa.eu/en`

In 2017, UDIT[7] (Use Open Research Data in Teaching) was built to provide and assist higher education instructors in incorporating open research data as well as other open science concepts into teaching to enhance the educational process. Other platforms such as TuvaLabs[8] can be used to improve data analysis skills at the primary school level. Teachers and students can use this platform to work with large data sets in various graphical representations, apply mathematical and statistical concepts to data, and construct, analyze, and interpret linear or non-linear relationships.

Researchers have also experimented with various digital platforms to increase the accessibility of open data in higher education. Irene et al. [50] created content for a digital game using open data sets and establish an educational environment to boost students' understanding of data concepts. To create content for a Monopoly clone called Geoplay, the researchers used Wikipedia data and devised a game-based learning experiment. The goal of the study was to determine whether the game (based on open data) would have any effect on the students' performance. The results indicated that after playing the game, students' progress with and understanding of data significantly improved. During the COVID-19 pandemic, students also evaluated the digital version of the game based on open data, with results showing that students found the game more appealing and rewarding than a traditional geography lesson.

Similar studies have also been conducted: Friberger et al. [51] developed the Open Data Monopoly game, which visualizes publicly available data for students about their countries and communities, while authors in [52] discussed the design of a card game using open data to teach climate issues to elementary school students. In comparison with traditional education, the studies showed how a game based on real data sets may increase students' interest in the subject and improve their performance and participation in the course.

In order to fill the gap between the open data potentials and its use by teachers, the field needs an open data portal that could facilitate educational activities without the need to spend time searching and filtering relevant educational open data sets through national open data portals and linking the school subjects with these educationally relevant data sets.

3.2 Existing sensors for school education

Sensors are frequently used as part of a learning toolkit. Popular physical computing toolkits, such as, micro:bit [53], Arduino [54], and SAM Labs [36], provide engaging ways of experimenting and programming with sensors. The Think Active project also explains the benefits and drawbacks of using

[7] https://site.uit.no/opendatainteaching/

[8] https://tuvalabs.com/

wearable sensors in school to allow students to reflect on their physical activity [55]. TEEMSS2 [56] and Pollen [57] are also two well-known projects in this regard. While participating in physical science projects involving temperature, sound, and plant growth, elementary school students can use sensory perceptions and sensors to investigate environmental rules and attributes. Both projects use an inquiry-based approach to help children transition from everyday practices to scientific perception to fill the gap between concrete and conceptual thinking [58].

The goal of the Appalachian State University program, "EcoSensors for Mountain Classrooms[9]" in collaboration with school teachers, is to integrate advanced digital sensor technology into the classroom. The program focuses on assisting students in developing their knowledge of local environmental issues such as stream water quality through the use of digital devices. The program provides K-12 students with outdoor learning opportunities to investigate environmental science concepts in real-world situations using skills such as inspection, measurement, and analysis.

The advancement and availability of low-cost geospatial technologies (GST) allow for the instructional use of web applications such as Google Earth and the Global Positioning System (GPS) to improve geospatial cognition as part of geography lessons. These GST, along with sensors (for example air and water sensors, cameras, and audio recorders), can be integrated into educational projects and school curricula [59, 60]. Students can use sensory experiences and sensors to choose, procure, analyze, and share geo-referenced information about various environmental aspects in the school context, such as water, noise, air, and water properties as well as civic equipment.

Companies such as Pasco[10] and Vernier[11] provide data collection technologies and innovative experiments for school education, such as wireless sensors. The wireless sensors use Bluetooth technology to display live, interactive data and can easily sync with Mac and Windows, smartphones, tablets, and Chrome books. However, research is still needed to investigate diverse ways for integrating sensors into the school curriculum to equip the younger generation with digital and data skills.

4 Summary

Given the current availability of data sets and the development of classroom technologies, such as sensors, interfaces, and data collection software, the younger generation must be educated in fundamental digital and data skills. To reap the benefits of these resources, however, we must first explore and

[9] https://sites.google.com/site/appecosense/

[10] https://www.pasco.com/

[11] https://www.vernier.com/

investigate how these resources can be integrated into school education. The challenges and requirements must also be addressed for these resources to be successfully integrated into schools, thus facilitating both teachers and students in their educational activities.

Chapter 3

Problem formulation

1 Problem formulation

Access to freely available data sets and technology opens up a plethora of opportunities in all aspects of life, including the educational sector. To date, however, open data and sensor data are mostly used in higher education, with little research being conducted in secondary school education. The work presented in this dissertation aims to investigate the following question:

"How can open data and sensor data support teachers and students in the educational process and how to design and develop an open data platform to support secondary school education?"

2 Contributions of the papers

Part II summarizes each paper's contribution to the solution of the problem as well as its relevance to the problem. In the following, each paper is discussed briefly, along with its significance to the problem.

Chapter 4: Open data visualization in Danish schools: A case study

The sub-problem addressed in this paper is how open data visualization engages students' attention in subjects such as mathematics, science, and geography from the standpoint of teachers in elementary and secondary school education, discerned through interviews. The basic concept of the study is to look at Denmark's national open data portal and existing open-source tools that can be used for visualization. The analysis provides an overview of data sets that can be used in instructional activities and describes how to visualize these data sets so that students can relate them to their subjects. These visualizations were used in a survey of Danish school teachers to determine how open data visualizations could be implemented in schools and what the potential benefits and challenges would be from an educational standpoint. According to the findings, introducing open data visualizations into schools has the potential to make everyday teaching more interesting while also aiding in the improvement of digital and data skills.

Chapter 5: Bringing open data into Danish schools and its potential impact on school pupils

This paper identifies several applications for open data in education. Copenhagen's open data domains are categorized under educational themes. These topics were presented to instructors and students in interviews, open discussions, and a pilot test with seventh- and eighth-grade students. The findings show that the use of open data not only allows students to learn real facts about their communities, improves civic awareness, and develops digital and data skills, but that such usage also allows them to think of ideas to improve their communities. Various challenges were also identified during this study, such as the fact that the data concept is too abstract for many students and that they require hands-on experience with data-collection activities. Most teachers are also unaware of open data and how to incorporate such data into their educational plans.

Chapter 6: Enterprise architecture oriented requirements engineering for the design of a school friendly open data web interface

This article presents an open data web interface design and prototype for Danish public schools using the "enterprise architecture oriented requirements engineering" (EAORE) technique proposed in a previous study [61] on open data utilization as an educational resource. This paper is an extension of the previous work [61]. The contribution consists of a systematic literature review on the use of open data in various educational sectors, the identification of a research gap in exploring the educational opportunities provided by open data, and the design and prototyping of an open data interface (ODI) proposed as a result of EAORE.

Chapter 7: Open data interface (ODI) for secondary school education

In this study, the usability of the ODI was examined and tested. The findings show that the ODI can help bridge the gap between the educational potential of open data and its widespread adoption in educational activities. We also identified how data collection and analysis can be integrated into school education using openly available data sets with qualitative and quantitative research methods. According to the findings, the use of open data can potentially improve future generations' digital and data skills, as well as help students, understand their surroundings by incorporating real data sets into their studies. The results also show that the ODI helps instructors use open educational data sets in the classroom.

Chapter 8: Towards using sensors as data sources in teaching: Requirements for school curricula-compatible sensors

In this study, we used qualitative and quantitative research methods to define the requirements for school curriculum-compatible sensors, particularly for secondary school students in grades 5 through 9. We also designed requirement models for sensor classes that meet school curriculum compatibility standards using various engineering methodologies. The findings indicate that incorporating sensors into schools can help students improve their digital and data skills. The use of requirements models can also aid in the development of school curricula-compatible sensors and the transformation of existing sensors into curricula-compatible sensors.

Chapter 9: Digital innovation in education: Perspectives, opportunities, and challenges of educational open data and sensor data

This paper discusses the perspectives, future opportunities, and challenges of using educationally relevant open data and sensor data to create new digital and data innovation possibilities in secondary schools, as well as addressing the challenges of a digital shift in this digitization age.

3 Conclusion on Part I

This concludes the introductory section, which includes an introduction (Chapter 1), background (Chapter 2), and problem formulation, as well as an outline of the contributions for each paper, as noted above. The following section contains the papers that comprise the dissertation's main content.

Part II

Papers

Chapter 4

Paper 1: Open data visualization in Danish schools: A case study

Mubashrah Saddiqa, Lise Lykke Le Maire Munksgaard Rasmussen, Rikke Magnussen, Birger Larsen, Jens Myrup Pedersen

The paper has been published in the
Proceedings of 27th international conferences in central Europe on computer graphics, visualization and computer vision: Proceedings – Part II. red. / Vaclav Skala, pp. 17–26, 2019.

Abstract

Increasingly public bodies and organizations are publishing open data for citizens to improve their quality of life and solving public problems. But having open data available is not enough. Public engagement is also important for successful open data initiatives. There is an increasing demand for strategies to actively involve the public exploiting open data, where not only the citizens but also school pupils and young people can explore, understand and extract useful information from the data, grasp the meaning of the information, and visually represent findings. In this research paper, we investigate how we can equip our younger generation with essential future skills using open data as part of their learning activities in public schools. We present the results of a survey among Danish school teachers and pupils. The survey focuses on how we can introduce open data visualizations in schools, and what are the possible benefits and challenges for pupils and teachers to use open data in their everyday teaching environment. We briefly review Copenhagen city's open data and existing open-source software suitable for visualization, to study which open-source software pupils can easily adapt to visualize open data and which data sets teachers can relate to their teaching themes. Our study shows that introducing open data visualizations in schools makes everyday teaching interesting and helps improving pupils learning skills and that to actively use open data visualizations in schools, teachers, and pupils need to boost their digital skills.

Keywords

Open data; visualization tools; interactive visualizations; educational resource; pupils.

1 Introduction

Open data is freely available data for anyone to use, share and re-publish anywhere and for any purpose. Mostly, open data is published by governments, public sectors, researchers, and organizations such as data about transport, budgets, business, environment, maps, science, products, education, sustainability, legislation, libraries, economics, culture, development, design, and finance. Open data has the power to revolutionize and disrupt the way societies are governed. Being used in different sectors on a wider scale, there are many examples of how open data can save lives and change the way we live and work [62]. Organizations in many countries are beginning to publish large data sets which are open for the public. But, the availability of open data alone is not enough to ensure that it is made use and brings useful results. Without some form of aggregation, it can be hard for users to make sense of open data and understand it if they have no or little experience in processing and data analysis.

Visualizations play an essential role as they are an effective way of interacting with large amounts of data from different fields, ranging from history [63] to economics [64] to basic science [65]. It provides a powerful means both to make sense of data and to present what has been discovered. With the advent of new interactive visualization techniques, the presentation of data in a pictorial or graphical format makes it easier for a layman to understand large data sets [66]. Presently, visualizations are widely used in news, books, the internet, health, and economics [67] and having limited knowledge of visualization can be a serious handicap.

As, society as a whole, is becoming increasingly digitized, it becomes essential to develop new research and educational models in schools to improve data-based digital competencies among students [68]. Many European countries have acknowledged the potential of digital competencies [69], and several have taken steps to introduce open data in schools and have started open data projects, e.g., open data for education competition in Northern Ireland with the intentions to use existing open data to assist teaching in primary and secondary schools [1].

The concept of open data can be made more interesting for school children and pupils by introducing visualizations and they may understand its potential and respond more quickly when exposed to visualization techniques. Therefore, to optimize the engagement of the young generation with open data, they must be familiarized with visualization tools, (e.g., charts, geographical maps and other types of representations) at an elementary level [70]. These simple visualizations become more powerful if they are created in relation to open data from domains that are of importance to the pupils, e.g., using data from their city to detect and understand problems that are pertinent to their local area and everyday life [28].

With the availability of open data, new opportunities arise for all kinds of organizations, including government agencies, not-for-profits, and businesses, and allows them to come up with new ways of addressing problems in society. These include predictive health care [71], improving the transport system [72, 73] and transparency [74]. Open data also opens up a wide variety of mostly unexploited possibilities of their use in education, e.g., in the form of visualizations. Although attention on visualization literacy [75, 76] continues to grow in different disciplines [77] there is still an ongoing discussion of the relative merits of different visualization platforms [78,79]. Several studies [80, 81] illustrate people's limited knowledge in understanding data visualizations, indicating the urgency to address the problem. Recent studies [82, 83] pointed towards defining tactics to value visualization literacy,

[1] https://www.europeandataportal.eu/en/highlights/open-data-schools

while others addressed how to improve it, using basic pedagogic ideas. Although many new teaching models [84, 85] have been presented to increase visualization literacy among the public, not much attention is paid to the ground level, i.e., schools. Open data visualizations [86] based on local information can not only help to make visualization literacy easy and interesting but can also improve civic awareness and learning behaviors among pupils. Large and complex open data sets can be further simplified and visualized for use in the teaching of, e.g., basic physics, mathematics, and statistical methods, geography, social science, and data handling in general. These data sets not only make the teaching interesting and interactive but also develop skills among pupils to understand and ask questions about different facts of their local areas.

In this research work, we reflect on the importance of open data visualizations on educational aspects, e.g., how open data visualizations can best facilitate education, what are the required skills to work with open data and its presentations at the school level, and what would be the constraints and problems when working with open data visualizations at a basic school level? We address the following research questions:

- What would be the benefits of introducing open data and its visualization in the teaching tasks?
- How can open data visualizations be used in education especially at the school level?
- How can visualization facilitate understanding of open data in the educational domain?
- Which tools are considered user-friendly and effective in visualizing open data in schools?

We present results from a survey addressed to pupils and teachers to investigate these research questions. We briefly review the open data of the City of Copenhagen through its open data platforms. To visualize open data at a school level, we also analyzed the user-friendliness of existing visualization technologies. We visualize concrete open data sets of Copenhagen using existing visualization tools and presented the results to school pupils and teachers. These specific open data visualization examples are used during the interviews to provide a reference on how teachers could relate to them as part of their teaching. Their feedback is used to identify the interesting open data sets, challenges, and problems that need to be tackled to work with open data visualizations in the schools.

The paper is organized as follows: Section 2 describes the motivation and methodology. Section 3 presents the analysis of the open data sets of the City of Copenhagen with some suggested educational open data sets corresponding to specific educational domains and a short review of existing visualization techniques. Section 4, describes the setup and results of the pupils-teachers survey. The conclusion of the study is given in section 5.

2 Motivation and methodology

There is an increased number of governments and companies using open data to offer new services and products to the citizen, which signaled open data as one of the building blocks for innovation. Using open data effectively could help to save hours of unnecessary waiting time on the roads and help to reduce energy consumption. Using open data, newly developed mobile applications aim to make our lives a little easier, and by using these applications we could have access to real-time information to minimize travel time, e.g., MinRejseplan [2] mobile application in Denmark. To equip our younger generation with the required digital skills for future challenges, it is important that teachers are aware of and able to use open data as an educational resource that allows them to develop data and digital skills among the younger generation of pupils.

Denmark is one of the leading countries with the most up-to-date open data. Denmark has a national platform [3] for the cities to publish open data, providing a common entry point for accessing open data. According to the Digital Economy and Society Index (DESI) 2018, Denmark is among the most digital countries in Europe[4]. The report documents that 94 percent of the country's public facilities and services are online and are highly advanced. Copenhagen, the capital of Denmark, is also famous for its smart city initiatives. The city has a large collection of open data available for its citizens. But, the social impact of open data is very limited due to the lack of public awareness according to open data Maturity report 2018 [87]. Therefore data literacy becomes imperative for the citizen of Denmark especially for the future generation, to make use of and contribute actively to the improvement of digital services.

There is a growing demand to take initiatives that aim at advancing digital skills and creating new interactive learning and teaching resources at the school level. Open data can act as an open resource that can facilitate teaching with real information and allows pupils to develop data and digital skills. In this research work, we focus in particular on how to create understanding and representation of open data as an educational resource for public school pupils. We focus in particular on the city's many types of data and how to

[2] https://www.nordjyllandstrafikselskab.dk/Billetter---priser/MinRejseplan

[3] http://www.opendata.dk/

[4] http://ec.europa.eu/information_society/newsroom/image/document/2018-20/dk-desi_2018-country-profile_eng_B43FFE87-A06F-13B2-F83FA1414BC85328_52220.pdf

put them into use especially in an educational context. For example, there may be data about traffic, pollution, light and the use of different areas and facilities. These data sets can easily relate to different subjects, such as science, mathematics, or geography subjects. At the same time, it is possible to compare these data with other areas of the city.

To understand how open data visualizations facilitate educational activities we surveyed Danish public schools in Copenhagen. The survey is conducted from August 2018 to December 2018. Six Danish public schools, 10 school teachers, and 21 school pupils of 7th grades aged between 13-14 years participated in the survey. The survey is formulated over interviews, questionnaires, and observations. The detailed methodology is discussed in Section 4. To investigate the research questions through our survey, we further sub-divided the research questions into three categories.

The data perspective:

- What would be the benefits of introducing open data in the teaching tasks?
- What types of data are already used in the schools?
- What would be the most interesting open data sets?
- What benefits do teachers think open data visualizations could have?

Teachers/Pupils competencies perspective:

- Which skills and competencies do pupils and teachers already have in working with data and presenting them?
- Which skills and competencies would be necessary for pupils and teachers to work and present open data?

The visualization's tool perspective:

- Which visualization tools are appropriate and easy to adapt for school teachers and pupils?
- Which visualization tools do teachers already use in their teaching?
- What are the possible challenges in adopting new visualization tools, e.g., language barriers or installation of the systems?

To identify perspectives on teachers/pupils' skills and competencies, we collaborate with Danish public school teachers and pupils to learn their views about bringing open data into their classrooms and to identify skills they already have. The details are discussed in Section 4. To investigate perspectives about data and visualization tools, we reviewed and analyzed the open data sets of the City of Copenhagen and identified which domains of open data could be used in the different domains of education, e.g., mathematics, science, and geography. We also make a comparison of different available user-friendly visualization tools to find out which of them could be the best option for school teachers and pupils or if there is a need to develop open data visualization interface specifically for schools.

In the next section, we will briefly review open data sets of Copenhagen to discover possible data sets which can be used as part of different subjects in schools and contains interesting information about the city and its local areas. And we analyze user-friendly visualization tools to identify those we could adapt for the rest of the survey.

3 Analysis of open data sets and user-friendly technologies

In this section, we first analyze the open data sets of Copenhagen city to categorized open data themes corresponding to different educational domains, e.g., science, mathematics, geography, and social science. To utilize open data in education, we also focus on the availability of the data sets, data formats, and data types. Next for visualization of open data, we analyze existing user-friendly visualization tools and discuss their main features.

3.1 Open data of Copenhagen

The Copenhagen open data website [5] has a large number of data sets from all over the City. There are data sets, for example on traffic, parking, the city's physical infrastructure, as well as data on population, culture, and education. More than 280 data sets are available in different formats and can be found on the Copenhagen city website. To make use of open data using visualizations at the school level, it is important to understand the different formats and characteristics of data sets. The open data of Copenhagen city can be categorized into ten general themes. These general themes of open data with corresponding sub-domains are listed in Table 4.1.

The data sets include static data, dynamic data, geographical and live data in different formats. In Table 4.2, the main characteristics of the open data of Copenhagen city are presented. Most of the data sets are up-to-date and timely processed. The statistical contribution of major themes of Copenhagen city is shown in Figure 4.1.

[5] https://data.kk.dk/

Table 4.1: General themes of Copenhagen open data

General Themes	Sub-domain
Environment	Nature, Water Quality, Air Quality, Pollution, etc.
Governance	Demographics, Elections, Census, Transparency, etc.
Health & Care	Social care, Care Homes, Child Care, etc.
Infrastructure	Roads, Buildings, Locations, Planning, etc.
Transport	Traffic, Parking, Transport, Pedestrian, Cyclist, etc.
Community	Society, Housing, Employment, etc.
Education	Schools, Kindergartens, etc.
Energy	Solar Energy, Consumption, Carbon Emission, etc.
Culture & Sports	Entertainment, Tourism, Cultural Locations, etc.
Economy	Finance, Economy, etc.

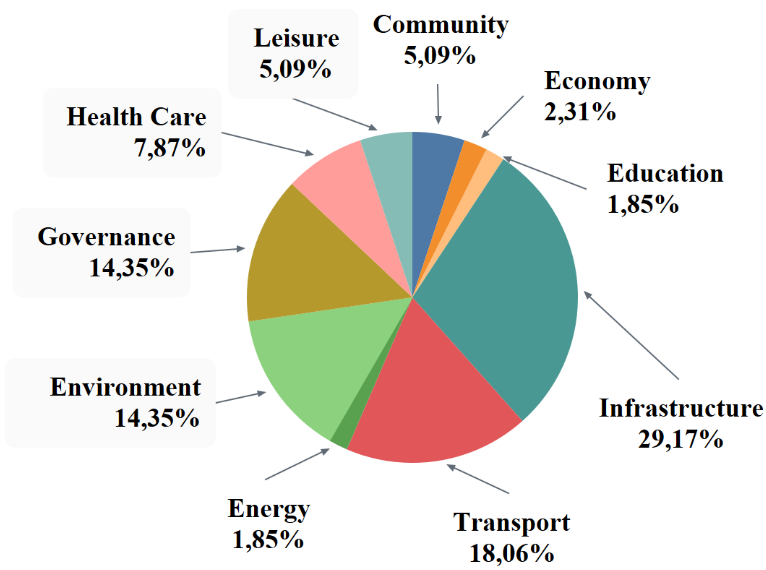

Fig. 4.1: Statistical view of open data general themes

Table 4.2: Characteristics of general themes of Copenhagen open data

General Themes	Data Types	Format	Datasets
Environment	Live/Sensors, Multi-dimensional	CSV, EXCEL	33
Governance	Statistical, Multi-dimensional	CSV, EXCEL, SHP (Shapefile)	22
Health and Care	Statistical	CSV, EXCEL	17
Infrastructure	Geographical, Live/Sensors, Statistical	CSV, EXCEL, DWG (Drawing)	63
Transport	Live/Sensors, Statistical	CSV, EXCEL, KLM, GeoJson	39
Community	Statistical, Historical	CSV, EXCEL	29
Education	Statistical	CSV, EXCEL, GeoJson	5
Energy	Live/Sensors, Statistical	CSV, EXCEL, KLM	4
Culture & Sports	Statistical, Historical	CSV, EXCEL	9
Economy	Statistical, Historical	CSV, EXCEL	9

Table 4.3: Open data educational themes and corresponding domain

Educational Domain	Educational Themes	Examples
Science Subjects	**Environmental Data**: Pollution, water quality, traffic, carbon Level, energy, etc.	To view the city's pollution within the city, e.g., carbon level.
Mathematics	**Statistical Data**: Gender, population, age, housing, education, etc.	To make comparison of different details, e.g., gender comparison.
Geography	**Geographic Data**: City distribution, Buildings, Roads, Locations, etc.	To view the locations of buildings, roads and areas etc.
Social Science	**Demographic Data**: Education, nationality, income, work, culture, etc.	To view the details about population, age, income, employment and education etc.

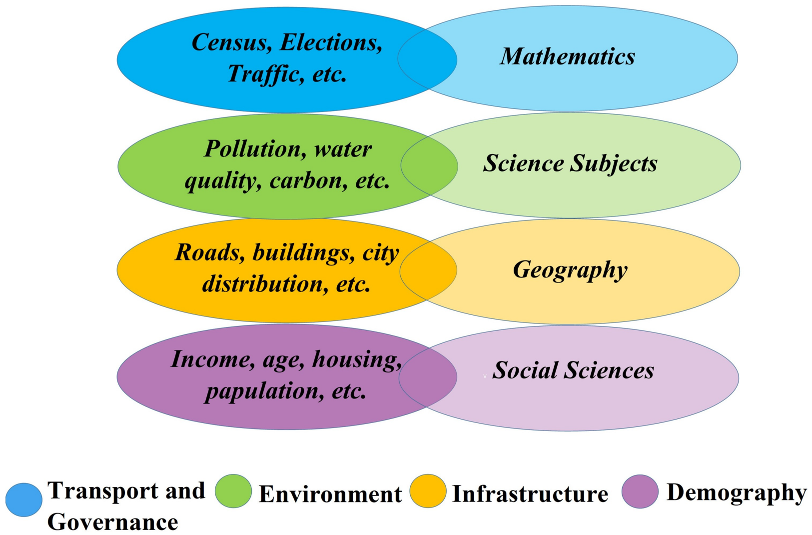

Fig. 4.2: Example of open data themes corresponding to educational domains

This brief analysis will enable us to identify some of the relevant data categories which will be used as part of specific educational domains. The open data review of the city enabled us to explore 4 impact domains (educational themes) discussed in [19] with associated sub-domains corresponding to main educational domains, i.e., mathematics, science, social science, and geography.

Figure 4.2, represents the possible mapping of open data educational themes to the educational sector. Table 4.3, presents different sub-domains of open data (educational themes) and examples of their possible use corresponding to specific educational domains. This analysis will enable us to ask teachers which of the different available data sets and formats can be used during teaching tasks, which data sets are interesting, and how they could be used as an aid to make teaching tasks more interactive.

3.2 Review of user-friendly visualization tools

A large number of data visualization technologies have been developed over the last decade to support the exploration of large data sets. However, to interact with open data, it is important to visualize it. For this, visualization technologies and software are required, which are user-friendly, need no programming knowledge, and are supposed to be simple to use if used by the school teachers and pupils. According to The Tech Terms Computer Dictionary [6], user-friendly means a software interface that is easy to learn and easy to use. It should be simple with easy access to different tools and options, and with minimal explanation for how to use them. For school pupils, We are interested in tools that are

- user-friendly
- needs no coding/programming requirements and
- supports the most common formats, (e.g., CSV, Excel, Google sheets, etc.)
- provides a platform where teachers and pupils can share their visualizations
- provides a public forum for inspiration, collaboration with others, and share experiences
- provide a free license for pupils and teachers

We analyzed six different tools which are often used for visualization purposes. In the next sections, we discussed their main features and compare them to one another based on the criteria defined above to find the best possible tools adapted for visualization at school levels. The comparison is given in Table 4.4.

Table 4.4: Comparison of commonly used open source software based on defined criteria

Tools	License	Academic Program	No Programming	Online Site	User Friendly	Public Forum
Tableau	x	x	x	x	x	x
QlikView	x	x	x		x	x
Power BI	x		x		x	x
Excel	x		x		x	x
Data-Wrapper	x		x		x	x
Google Maps	x		x		x	x

[6] https://techterms.com/definition/user-friendly

Tableau

Tableau[7] is a data visualization tool and provides different products with a one-year free license under its academic program. The academic suite includes:

- Tableau Desktop
- Tableau Prep
- Tableau Online
- Tableau public to collaborate with others visualizations and experiences
- Customer support and community forum

Tableau Desktop is used to connect with various types of data and for creating visualizations. Tableau Prep transforms data for analysis and allows users to combine and clean data before visualization. With Tableau Online pupils can easily share and collaborate their work by uploading workbooks to a site managed by instructors. Sites are issued for 1 year and allow for 100 simultaneous users. There is no need for any coding knowledge to work with Tableau.

QlikView

QlikView[8] is a user-friendly, interactive open-source visualization tool with no requirements of coding knowledge. Visualizations can be shared with up to 5 users. It is compatible with default and custom data connectors and also imports data from popular databases. Qlik also provides an academic package for students and teachers which includes the following resources:

- Qlik Software
- Qlik Continuous Classroom online learning platform
- Data Analytic curriculum featuring lecture notes, on-demand videos, handouts, activities, and real-world, interactive business use cases
- Qlik Community-Academic Program Space, a forum for professors and students to access resources, collaborate with others and share experiences

[7] https://www.tableau.com/

[8] https://www.qlik.com/us/products/qlikview

Power BI

Power BI[9] is a collection of software services, apps, and connectors that work together to turn data into interactive visualizations without any programming knowledge. Power BI easily connects to different data sources. Pupils can get a free limited version of Power BI but not an academic program with full resources. BI also provides a public forum to collaborate with others but it does not provide a separate free site managed by instructors to collaborate with their pupils.

Excel

Excel[10] is part of the well-known Microsoft Office suite and also supports data analysis. One of the greatest advantages of Excel is its flexibility, as it puts little or no constraints on the user's ability to create visualizations. Excel does not provide specific academic programs. No programming knowledge is required for visualization purposes. Excel also supports commonly used formats, (CSV, Excel, and sheets, etc.). Excel provides low barriers and sufficient tooling, but it stops at a medium data level.

Datawrapper

Datawrapper[11] is a user-friendly and mobile-friendly data visualization tool. No programming is required for visualizing data. It supports 10,000 monthly charts to publish. It is compatible with CSV, Excel, and Google sheets and provides a community forum to share experiences and problems with others but there is no academic program for pupils or teachers.

Google Maps

We also list **Google Maps** as a visualization tool because geographical data can easily be visualized using Google Maps. In addition, it is a familiar tool for pupils and teachers and most are already familiar with many of its features, e.g., from planning travels, finding locations, and receiving traffic information. It is also user-friendly and requires no programming skills.

We selected Tableau and Google Maps as the visualization tools, which we used as examples during the interviews. Tableau fulfills the required criteria and Google Maps is a good option as teachers and pupils are already familiar with its features and functions.

[9] `https://powerbi.microsoft.com/en-us/`
[10] `office.microsoft.com/excel`
[11] `https://www.datawrapper.de/`

4 Pupils-Teachers survey

In order to identify the teacher's perspective on the role that open data visualization can play for school pupils, we surveyed Danish public school teachers and pupils. The survey includes interviews with teachers and a two-day pilot test with school pupils and teachers.

4.1 Participants

For the teachers' study, we recruited 10 teachers from 6 different Danish public schools. The teachers were identified according to their subject, experience, and age. The focus subjects were mathematics, science, and geography. The teachers have teaching experience from 3 years to 15 years in the above-mentioned subjects and were aged between 25-45 years. For pupils' study, we ran a pilot test for two days in one of the Danish public schools. Two (science and maths) teachers along with 21 students of 7th grade, aged between 13-14 years old participate in the pilot test.

4.2 Setup

Before the interviews, we delivered presentations of about 10 to 15 minutes on open data and its visualization using data sets containing local information about the neighborhood around each school, and their possible usage at the school level as part of mathematics, science, or geography. For instance, data sets about the areal distribution of the city can provide interesting information for a geography class.

We transform bigger data sets within different themes into smaller data sets to present the local information relevant to respective school locations using Tableau and Google Maps.

For example, Figure 4.3, represents Copenhagen distribution into different parts, each with a unique color and further divided into smaller districts. It can be an interesting visualization for school pupils as they can locate their local areas easily. Figure 4.4 represents statistical details of Tingbjerg (district of Copenhagen) e.g., population, education, low and high income. Using Google Maps, we visualize locations of the city's public schools according to their postal code numbers as a specific example for teachers and pupils. School pupils can use this map to get directions and measure the distance of their schools from their homes, different routes to their schools, more information about schools, e.g., schools website and address.

These visualizations formulated over the local area information near the school will help teachers to understand what type of data and information they could present to pupils during their teaching tasks as part of mathematics, science, and other related subjects.

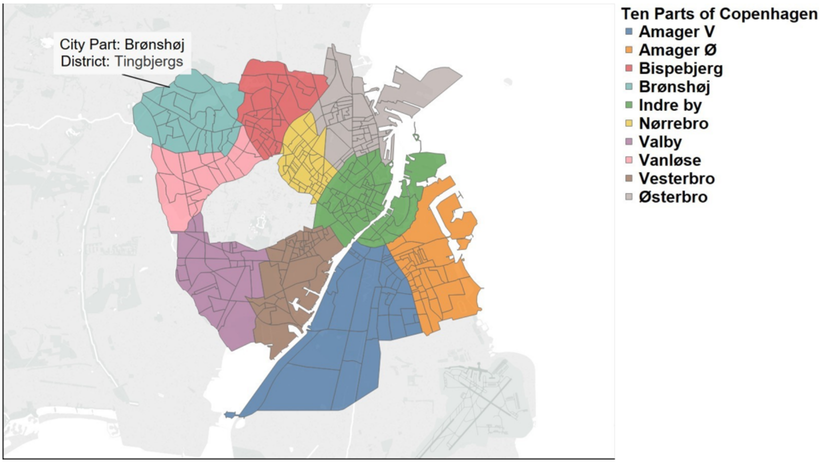

Fig. 4.3: Areal distribution of Copenhagen

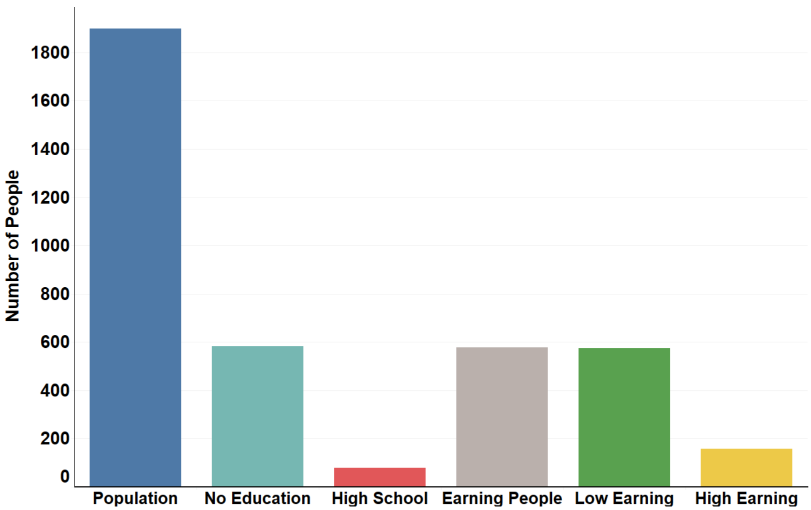

Fig. 4.4: Statistical details of Tingbjerg

For the pilot test with pupils, we requested the school administration to install the free academic package of Tableau on pupils' and teachers' computers. We provided teachers (mathematics and science) beforehand with some specific visualizations which they could relate with their subjects, e.g., the pollution level in different parts of the city at different times of the day, traffic passing through their areas at different parts of the day, the population details including age, education, and gender details. We also designed activities to explore the information through these specific visualizations, e.g., to find the carbon level of their area in morning and evening time, to find the gender details of their area, etc. Pupils were also given a presentation, where we presented the visualizations of the data sets from the educational open data themes given in Table 4.3, using Tableau.

4.3 Procedure

To investigate our research questions in different aspects discussed in Section 2, we conducted a teachers and pupils survey. The teachers' study was carried out with individual participants. Before the interviews, the participants were given a small introduction to open data and how they can adapt it as part of teaching tasks. We also asked both teachers and pupils for their consent to participate in the research work using video and audio devices. We used the Danish language for both teachers' and pupils' study.

Teacher's study

To achieve the best possible results and feedback on the three perspectives of our research questions, i.e.; the data perspective, the teachers' perspective, and the visualization tool perspective. We divide the teacher's study into three sessions, each session with 30 to 40 minutes. The overall time for teachers' study is 1.5 to 2 hours. To investigate the data perspective, in the first session, we presented short presentations of open data and its visualizations, existing open data sets of Copenhagen according to the location of, the schools and its possible usage at the school level as part of mathematics, science, and geography subjects. To identify the visualization tools perspective, teachers tested the visualization tool Tableau and tried to visualize some of the ready-to-use open data sets in the second session of the study. This will help us to identify which competencies teachers need when working with open data visualization and how convenient is it for the teachers to use. This is used as a background to investigate if they can use Tableau as part of their teaching. Teachers were provided with personal assistance to understand some main features of Tableau and Google Maps. In the third session, the focus is given more on the teachers' perspective. We asked participants to fill out a questionnaire and answer several semi-structured questions which elicit their views about the following perspectives.

Data perspective:

We asked questions about data already in use and formats used for the presentation of data during teaching especially in mathematics, science, and geography tasks. What is the pupils' level of understanding data in different grades?

Teachers perspective:

How does open data visualization facilitate education in schools? What will be the possible impact on their teaching environment and the school pupils with the use of real examples using open data visualization? What are the teachers' views about the skills pupils need to work with open data and its presentation?

Visualization tools perspective:

We investigate the adapting of visualization tools Tableau and Google Map in order to visualize open data in a simple way. Whether they encountered any technical issues or limitations of the visualization tool? What will be the possible challenges and problems?

In addition, we asked several semi-structured and optional open-ended questions about the problems, and their suggestion to successfully introduce open data visualization into the educational domain.

Pilot test

The role of pupils is important to investigate how they work with data, what data sets are interesting for pupils about their areas, and how they interpret open data visualization. We ran a pilot test in a Danish public school with 7th-grade pupils aged between 13-14 years old. The pupils worked with open data in their physics/chemistry and mathematics lectures for two consecutive days. We presented a 5-10 minutes presentation about open data with the help of visualizations of data sets within educational themes. These include air pollution, carbon level, traffic around their area, and some population details of their area. After the presentation, teachers relate some of the visualizations as part of Chemistry, where they talked about air pollution and different gases responsible for the pollution. With the help of open data visualization, the teacher pointed to different areas where the pollution level is higher than the other areas, e.g., train and central bus stations. Similarly, the maths teacher also relates statistical data of the city to make comparisons.

On the second day, pupils were taught how to use Tableau. They were provided with small data sets to visualize. All these activities were observed and documented using videos and still photos. The pilot test ended with a questionnaire in the form of simple questions. We asked pupils about their understanding of different types of data formats, e.g., Excel, spreadsheets, CSV, and the types of graphs, e.g., line, bar, pie charts. Which type of graph do they understand easily? What are the interesting data sets about their city? Based on the input from teachers and pupils we also analyzed the three main issues.

4.4 Results

In this section, we discuss outcomes from the pupils-teachers survey. The following are the more salient points from their feedback.

Teachers/Pupils perspective

- Teachers can understand and describe the Copenhagen open data visualizations presented during the interviews.
- According to teachers describing the city using open data visualizations will bring new perspectives in school teaching and school pupils.
- Teachers already used tools like GeoGebra, Excel, and Google Maps for basic data handling and presentations.
- Pupils are already familiar with different types of graphical representations of data in mathematics and science subjects, e.g., lines, bar, and pie charts.
- The pupils are likely to learn more when working with actual data of their area using visualizations.
- The interactive visualization tools can help a lot in order to make things more clear and interesting for pupils, but they are relatively hard to use.
- Pupils needs both, the skills and the tools to actively work with open data as an educational resource.
- Teachers believe that pupils' involvement can be made more interactive during the class using real data and real examples.

Data perspective

- The data cleaning and preparing concepts are not often used in teaching.

- Pupils use mostly data in tables to make graphs. It is not seen as difficult to introduce other formats of data in teaching, e.g., CSV and Excel formats.
- Pupils can use statistical open data of Copenhagen to understand mathematical methods, e.g., to make the comparison of different real-life facts of their local areas.
- The teachers agreed that they can introduce different formats of open data particularly the CSV in 4th-7th grades and Excel format from 5th-7th grades in mathematics subject.

Visualization's tools perspective

- Teachers are comfortable with Tableau and Google Maps and believe that pupils can take benefits from these open-source tools.
- Pupils from grade 4th-7th are also used to Google Maps from previous teaching experience. It will give more meaning if they can make use of it in their daily life using open data, e.g., they can use open data to locate play areas on Google Maps to get directions and measure distances from their schools or homes.
- The open data visualization can play an important role in concretely explaining more abstract things.

4.5 Discussion

In order to fully enable school pupils to understand and work with open data visualizations, introduction to data formats, data preparation, and data cleaning concepts need to be introduced as part of their subjects for example in mathematics. Using open data visualization of different data sets, e.g., traffic, population, economy, and education, etc., of their city in subjects like mathematics, geography, and science class can give them a chance to work with actual data. For example, presenting pollution level near the school at different periods of the day not only makes science class interesting but also improve civic awareness among the younger generation as the simple local visualization allow them to discuss why the level is higher at some periods and how they can reduce it. Using interesting statistics about pupils' age groups in different cities could help mathematics in understanding ratio and percentage problems with real data. Teachers are comfortable with Tableau as a visualization tool because of it's quite easy to use functionally without any coding and free licensing for pupils and teachers but they also point out some limitations, e.g., the extra time and efforts to visualize related open data sets. Google Maps is also seen as a good option for geographical representations and measuring distances or finding alternative routes and can be used as part of geography class. Based on the survey, we also identified some of the challenges. It can be hard for public school teachers to directly use the open data available at the city's open data portal. They will need ready-to-use data sets as part of their teaching subjects. Teachers need support and training workshops to use new visualization technologies at schools. The visualization tool Tableau and other open source tools are in English which could be a problem for public school pupils, but explaining some of the frequent functions in Danish can solve this problem. In order to bring open data in schools as an educational resource, our survey also suggests the development of a school-friendly open data visualization interface that provides local real information in the form of interesting and simple visualization in pupils' native language as part of different subjects.

5 Conclusion and future work

In this paper, we have presented a pupils-teachers survey as a first step, to study how open data visualization can be introduced in the schools to facilitate educational activities, which skills school teachers and pupils already have, and which visualization tools could be used to visualize open data as part of teaching subjects. Our study includes the visualization of Copenhagen open data sets, a review of existing user-friendly visualization techniques and software, and a qualitative survey of teachers and pupils. Based on our survey, we concluded that open data visualization can be brought into schools as part of different teaching subjects especially mathematics, science, and geography and it can play an important role in improving the pupils learning behaviors, as teachers and pupils can relate real problems from different perspectives in everyday teaching. To use open data visualization actively in different teaching subjects, teachers need to boost their digital skills, adopt new interactive learning and teaching resources as well as support the approaches for knowledge development. Insight from this study advances the knowledge of our community about what are the skills needed for schools teachers to use the open data visualization in their teaching areas and how the availability and literacy of open data visualization in schools create opportunities for school pupils to come up with new ways of addressing and understanding society's problems.

As future work, we are aiming to develop a school-friendly open data visualization interface that provides aid to teachers and pupils to visualize local area data sets within open data educational themes, compare these data sets with other areas, and suggest different activities for pupils as part of teaching tasks. We will first identify the needs and requirements for a school-friendly open data interface using the Requirements Engineering domain and then develop prototypes for testing and validation of the interface in the Danish public schools.

Chapter 5

Paper 2: Bringing open data into Danish schools and its potential impact on school pupils

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Abstract

Private and public institutions are using open and public data to provide better services, which increases the impact of open data on daily life. With the advancement of technology, it becomes also important to equip our younger generation with the essential skills for future challenges. In order to bring up a generation equipped with 21st-century skills, open data could facilitate educational processes at the school level as an educational resource. Open data could act as a key resource to enhance the understanding of data through critical thinking and ethical vision among the youth and school pupils. To bring open data into schools, it is important to know the teacher's perspective on open data literacy and its possible impact on pupils. As a research contribution, we answered these questions through a Danish public school teacher's survey where we interviewed 10 Danish public school teachers of grades 5-7th and analyzed their views about the impact of open data on pupils' learning development. After analyzing Copenhagen city's open data, we identified four open data educational themes that could facilitate different subjects, e.g., geography, mathematics, basic science, and social science. The survey includes interviews, open discussions, questionnaires, and an experiment with the grade 7th pupils, where we test the pupils' understanding with open data. The survey concluded that open data cannot only empower pupils to understand real facts about their local areas, improve civics awareness and develop digital and data skills but also enable them to come up with ideas to improve their communities.

Keywords

Open data; educational themes; impact; school pupils; educational resource.

1 Introduction

Cities are an essential part of the future global economy. In 2008, according to a United Nations report [88], more people lived in urban areas than in the countryside for the first time in history. It is also predicted that more than 75 percent of the global population will live in cities by 2050. To fulfill the citizen's needs, cities are adopting new digital services, which capitalize on new technologies and applications - which in turn generate vast quantities of data. This big open data has the potential to further advance the quality of living in cities in a myriad of ways [8, 89]. To meet the challenges of urban population growth, cities around the world are seeking to reinvent themselves, aiming to be able to respond to their citizens' needs [90] through efficient exploitation of big data.

The data generated as a result of citizen activism and the citizens themselves are an increasingly powerful resource [91]. Citizens are thus seen as active agents within the development process of a city. Generally, citizens are unaware of the data they are contributing and how they can take advantage of it. Open data gives the individual an opportunity to interact directly with data, but citizens need to possess the right skills and knowledge to benefit from this opportunity. Therefore, it is important to ensure that all citizens, especially the younger generations, are equipped with the skills essential to understand and make use of open data as they can bring a lot of value to the table when they are part of design and innovation processes [92].

In Denmark, more than 80 percent of the population lives in cities, and according to the 2018 Digital Economy and Society Index (DESI), Denmark is one of the most digital countries in Europe. Copenhagen, the capital of Denmark, is one of the top 20 smart cities in Europe according to a study carried out by EasyPark[1]. The city has a large collection of open data available to its citizens. To use this data and actively contribute to the improvement of digital services, open data literacy becomes imperatives for the citizen of Copenhagen. There are many examples of how open data can serve the public, e.g., the findtoilet.dk[2] service locate all the Danish public toilets so that people with bladder challenges can now feel more comfortable when going out. Similarly, mapumental[3] in the UK allows citizens more easily to find places to live, e.g., by estimating the duration of commuting to work and by having updated housing prices. As data is now a part of everyday life, it becomes the responsibility of the average citizen to have some level of data literacy and understanding to respond to public services effectively. Especially the young generation needs to learn how to work with data and develop digital skills. There is a growing demand to improve digital skills and introduce interactive learning and teaching resources at the school level [93].

This research work is part of the Community Drive research project[4]. The project is a technical and humanistic research and development project that aims to establish comprehensive data-driven research and development collaborations between urban planners and the younger generation via a focus on the education of children and young adults in the community.

Community Drive deals with the city's many types of data and the collection and usefulness of relevant data regarding the city, the citizens, and the current data usage. The project focuses on how young people can be educated to foster participation in the development of the city using open data and sensor data, and how they can be empowered to conduct data collection on their own and be taught to work with data documentation to represent their districts using various types of data. The project has three phases. Figure 5.1 illustrates the different phases of the project.

[1] `https://easyparkgroup.com/smart-cities-index/`
[2] `http://www.findtoilet.dk/`
[3] `https://mapumental.com/`
[4] `https://www.communitydrive.aau.dk/`

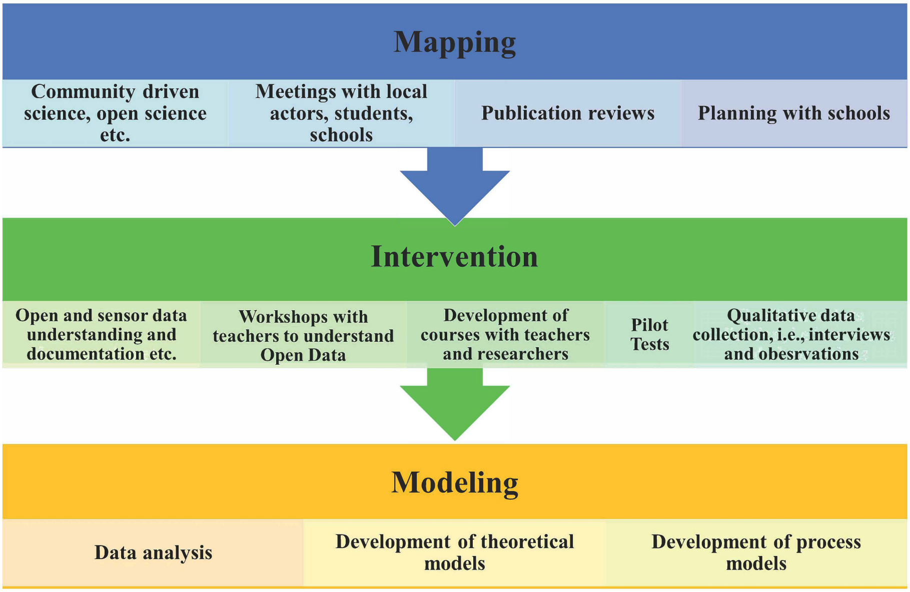

Fig. 5.1: Different phases of Community Drive Project.

In the first phase of the project, key opportunities and issues for the development of re-designed educational models for the collaborated schools in close collaboration with the respective school teachers will be identified. The project participants are school teachers and pupils of 5-7th grades aged between 11-13 years. In the second phase, the education process will be developed and pupils will test their new digital and design-based knowledge skills in the Southwestern part of Copenhagen, where the government has planned to launch the urban renewal processes to develop the Southwest neighborhoods of Copenhagen city. The final phase of the project compares data, results, and experiences from the two initial phases. Throughout the project, the pupils will not only develop their design-based knowledge but also work with various data types, including open data. Figure 5.2 represents the different steps for school pupils to identify problems in the neighborhoods and create proposals for solutions using open data. School pupils will, in particular, work with different types of the city's open data to understand different challenges and problems within their local areas.

To familiarize pupils with the different data types of the city in an educational context, teachers play a central role. In this research work, we are intended to design experiments to communicate with teachers and investigate possible approaches to introduce the concept of open data as an educational resource. In the current paper, we present results from a qualitative interview study with Danish public school teachers and analyze their perspectives on

Fig. 5.2: Steps for pupils to identify problems in the neighborhoods and to create proposals for solutions using open data.

the following research question:
"*How can we best introduce open data in schools, and what will be the potential impact on the pupils?"*

The structure of the paper is as follows. The central concepts are discussed in Section 2, followed by an analysis of the characteristics of Copenhagen's open data in Section 3. In Section 4, we discuss the method and key factors involved in the interview study. We present the key points from interviews for the successful implementation of open data literacy and its impact on pupils in Section 5. We finally conclude the work in Section 6.

2 Background

There is an ongoing emerging exploration in the technical areas of data analysis, machine learning, and visualization within the scientific community [94]. However, a minor contribution has been made around the humanistic side specifically when dealing with data. What are the skills and competencies that individuals need in order to understand and solve problems with data? What new skills and abilities must humans acquire in order to design, interpret and analyze complex data and visualization? As societies are becoming data-dominated, it becomes a necessity to train the younger generation with essential data skills for the success of future plans, applications, businesses, and smart cities.

Open data is creating new openings for people and societies, by improving not only efficiency and effectiveness of public services, creating jobs, and increasing government transparency [95], it can also act as a key, to develop digital and data literacy skills, enhance critical thinking, and civic awareness among students [16]. Open data are freely available data sets that anyone can access, use and share without the need for any license [96]. Open data is a potential resource of opportunities for the public, for example, providing better and efficient public services (real-time traffic applications, health, and environmental services, etc.). However, the educational aspect of open data is not fully exploited, e.g., to support learning activities using open data as part of different subjects. For instance, open data could be used as an educational resource at the school level to provide support in developing 21st-century skills among younger students, especially digital and data skills, critical thinking, civic awareness, etc., using the real information of pupils' surroundings. For this, it is essential to associate the effect of open data at the ground level, i.e., schools and the pupils.

In this research work, we are motivated to communicate with teachers and introduce the concept of open data as an educational resource at the school level. Previous studies show that primary educational institutions are facing the challenge of not sufficiently educating children and young pupils for independent knowledge design and for finding solutions to complex societal challenges [97, 98]. Previous work also indicates that the Danish elementary school is challenged by not sufficiently educating children and younger people to self-employed knowledge production and to develop a solution for authentic complex problems [99].

The Organization for Economic Co-operation and Development (OECD) and a number of private research funds focused on new practices for open research and open innovation that encourage participation in the research and development process from non-academic partners. Such open 'quadruple helix' collaborators involve representatives from research, businesses, authorities, and civil society and are considered in a number of publications as the key to the greater and more responsible use of research knowledge [100]. Open research is first and foremost a research agenda that can lead to greater research impact in society. This is emphasized at the same time by the strong growth in diversity and the amount of open data provided by public authorities [101]. Previously, highly specialized expertise was required to analyze big data, but now there are several tools that enable citizens and other laymen to independently work with big data analysis [102].

In order to enable children and younger people to interact and understand the concept of open data, it is important to introduce open data literacy at the school level. The main barrier to this interaction is the lack of problem-based education and engagement of school pupils in problem-based projects. They are not familiar with the open data and visualization technologies and their usage, and often open data may seem something for experts only. In order to enable pupils to make benefit from open data, data must be taught as part of different subjects. Thus, in order to know the pupils' competencies to work with open data, its impact on pupils' learning behaviors, and to figure out the possible challenges, it is crucial to know the teachers' perspective about open data literacy at the school level. In this research paper, we contribute with a teachers' survey and analyze the pupils' current data literacy skills and the possible impact of open data on pupils in their learning and everyday life. During the testing period of our project, we choose teachers and students from 5-7th grade as, in these grades, students start working with basic concepts of data and its presentation, as part of mathematics and statistics.

In the next section, we will briefly discuss the concept of open data with a brief analysis of the City of Copenhagen's open data to identify possible open data educational themes which could be used in different subjects as part of teaching activities.

3 Open data

According to Open Data Institution[5], the data that is made available by organizations, businesses, and individuals for anyone to access use, and share is called *open data*. The open data handbook[6] defines open data [3] as the data and the content that can be freely used, modified, and shared by anyone for any purpose. A city's open data continuously goes through many steps before it is transformed into valuable information. This includes the collection and the storage of data for further processing [103]. The key idea of analyzing open data is to extract meaningful information from this data, which can be used for the betterment of the community [104]. The data is examined and separated into different categories and formats to change it into meaningful information. Moreover, data visualization is essential for presenting the information to the public in a structured and easily accessible form. There is ongoing research by different organizations and researchers to study open data [105]. Open data can be static or dynamic. *Static data* does not change much over time, for example, locations of the bus stops, train stations, and collective or historical data. Historical or collective data contains data points noted over a long period. These data sets will help in observing trends and correlations. *Dynamic data*, on the other hand, is the real-time data or data which is constantly changing, e.g., traffic density and the number of available parking places. Some of the main characteristics of open data are completeness, availability, usability, non-propriety, non-discriminatory, variety, updated, persistent, and documentation as described in [62, 106]. Data quality and data formats are also among the important features of open data.

In the following section, we will discuss the Copenhagen open data to explore different data themes that could benefits pupils as part of different teaching subjects.

3.1 Copenhagen open data

The City of Copenhagen is the capital of Denmark. The city is divided into ten main parts and then further divided administratively into smaller districts. The city is famous for having the world's best strategy for the collec-

[5]`https://theodi.org/`

[6]`http://opendatahandbook.org/guide/en/what-is-open-data/`

tion and use of big data in order to provide the best digital services and to make the quality of life better[7]. The city has maintained a very good quality of open data covering all aspects of quality, i.e., more recent, accurate and accessible data. As part of this research, we consider two main open data sources of Copenhagen city, Open Data DK[8] and Open Data Copenhagen[9]. Both portals use the Comprehensive Knowledge Archive Network (CKAN) data platform for publishing the city's open data. CKAN is a web-based open-source data catalog system, which is used to manage the storage and distribution of open data. It is mainly used by public organizations seeking to share their data with the public. Currently, there are 20 publishers and most of them are different departments of the City of Copenhagen. After analyzing the available open data of the city, we categorized the open data into ten general categories. Table 5.1 presents the general categories with corresponding sub-domains. There are more than 290 available open data

Table 5.1: Copenhagen's open data general categories

No.	General Domain	Sub-domains
1	Governance	Elections, Census, Transparency, Demography, etc.
2	Environment	Pollution, Water Quality, Traffic, Climate, Nature, Noise, etc.
3	Health and Care	Social Care, Care homes, Child Care, etc.
4	Infrastructure	Roads, Buildings, Locations, Planning, etc.
5	Transport	Transport, Parking, Public Transport, Pedestrian, Cyclist, etc.
6	Community	Society, Housing, Employment, etc.
7	Education	Schools, Kindergartens, etc.
8	Energy	Solar Energy, Energy Consummation, Carbon Emission, etc.
9	Culture and Sports	Entertainment, Tourism, Cultural Places, Recreational Activities, etc.
10	Economy	Economy, Finance, etc.

sets. Figure 5.3 presents the distribution of open data sets within general categories of the City of Copenhagen's data. The data sets are of static, dynamic, and geographical types and are up-to-date and timely processed. In the following, we describe some of the general themes identified in the City

[7] https://www.europeandataportal.eu/sites/default/files/edp_analytical_report_n4_-_open_data_in_cities_v1.0_final.pdf

[8] http://www.opendata.dk/

[9] https://data.kk.dk/

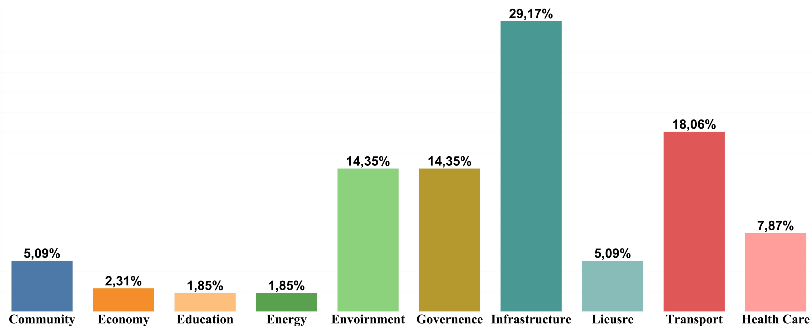

Fig. 5.3: Open data sets distribution among general themes of Copenhagen city

of Copenhagen open data. The description includes information about data types, data formats, and the number of data sets within the themes. This description will enable us to identify possible open data educational themes that could use as part of different teaching subjects.

Infrastructure:

This category, for example, includes data sets about the historical division of tax collection areas, currently used for statistical purposes. Data sets about schools, swimming pools, play areas, bottle containers, toilets, cultural houses, libraries, and other similar locations are included. The data sets are mostly static and are available in CSV, SHP, PDF, GeoJSON, and DWG formats. There are around 63 data sets from different sources and most of them are up-to-date.

Transport:

This category contains data about transport, i.e., traffic, roads, cycle paths, bus stops, bus routes, parking areas, traffic signals, and pedestrians. In total, there are 39 data sets within this theme - most of them collected through sensors. These data sets are available in CSV, XLS, GeoJSON, and SHP formats.

Governance:

This section contains information about local plans, elections, census, population, age, gender, income, and details about pension, insurance, and socioeconomic details. These data sets are also static in type and most of them are in CSV format. There are 31 available data sets.

Environment:

This section contains information about climate, pollution, carbon level, noise level, traffic pollution and about nature and trees in the city. The data sets include both static and dynamic data and are available in CSV, GeoJSON, SHP, DWG, and PDF formats. There are 31 data sets.

Community:

This category contains data sets mainly about education, employment, unemployment, and housing. The data sets are static and are available in XLS, PDF, and CSV formats and there are 11 data sets.

Health and care:

This category contains data sets social care, child care, and benefits distributed geographically, e.g., sickness, cash, job seeking, and flexible job allowance. The data sets are static and are in XLS and CSV formats. There are around 17 data sets under this theme.

There are open data sets covering other important categories, e.g., culture, art, youth, sports and entertainment, hospitals, and other public sectors. The brief survey of Copenhagen city's open data will enable us to present different open data sets which can be used at the school level as part of different teaching subjects. For example, data sets about the geographical distribution of the city, traffic details, pollution, and population could be used as real examples in geography, science, and mathematics subjects.

3.2 Open data themes corresponding to educational domains

We have carefully analyzed the main themes of Copenhagen's open data and produced 4 open data educational themes which can easily relate to specific educational domains, i.e., mathematics, science, geography, and social science. These include environmental data, statistical data, demographic data, and geographical data. Figure 5.4 represents open data themes with corresponding sub-domains which can easily relate to specific educational domains.

For example, environmental data can be used to view the city's pollution level, carbon level, and water quality at different parts of the city as part of physics and chemistry tasks. Statistical data could be used to compare different statistical details about population, age, and income when teaching mathematics or statistics. Geographical data could be used to view the geographical distribution of the city, roads, and locations, etc. as part of geography assignments. Demographics data could be used in social science

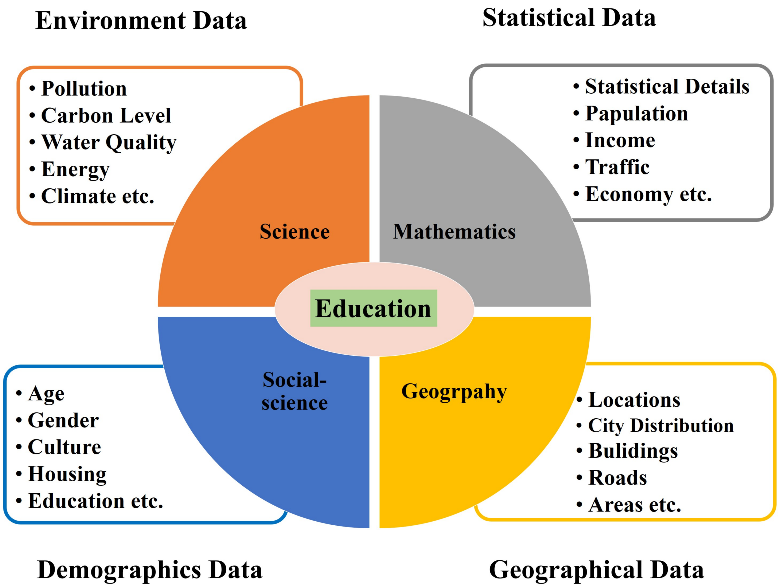

Fig. 5.4: Educational open data themes corresponding to specific educational domains

tasks to view the details of the citizen in a particular part of the area, their age, income, education and housing details, etc.

We will use specific open data sets from the educational themes, e.g., population, pollution, income, education level, and traffic data sets as examples during the interviews to understand the teachers' perspective about introducing open data as part of their teaching subjects and what would be the possible impact on pupils' learning abilities.

4 Method

To analyze the teachers' perspective about bringing open data into schools, its impact on pupils, and which competencies they need to collaborate with open data, we collected data through teacher's surveys and observing open data activities with pupils. For survey and observation, 10 teachers from 6 different Danish public schools and 12 school pupils of 7th grade aged 12-13 years, participated. We chose teachers from 5-7th grade as in these grades pupils start to develop basic concepts of data and its presentation as part of mathematics and statics. Table 5.2 shows an overall view of the participants. Teachers are identified according to their subjects, grade levels, experience, and location of the schools and the details are as follows:

Table 5.2: Overview of survey's participants

Participants	Number	Grades	Activity Type	Duration
Teachers	10	5-7th	Interviews, Questionnaire, Open Discussion	1.5-2 hrs
Pupils	12	7th	Observation	1-1.5 hrs

- Subjects: Mathematics, Science, Geography and Social Science
- Grades: 5-7th
- Experience: 3-15 years
- Age: 25 to 40 years, to get feedback from a range of perspectives, e.g., from young teachers to as well as senior teachers.
- Schools: Copenhagen public schools situated near the Southwestern part of the city where the future project will be carried out or other schools situated in similarly deprived areas.

For the survey, we interviewed public school teachers identified according to the criteria stated above. The structure of the interviews was both one-to-one and group interviews. Individual interviews were carried out with 8 teachers. Three teachers were interviewed as a group. The interviews were carried out in the Danish language with teachers' consent to record interviews using audio devices. The duration of interviews was 1.5 to 2 hours. At the beginning of the interview, presentations of 10-15 minutes on open data with use cases were presented to teachers followed by open discussions. After the presentations, the teachers were asked verbal and written questions in the form of an online questionnaire. To investigate the research question in different aspects, we sub-divided the research question into three categories:

Skills and competencies:

We asked teachers about how often they work with data in their teaching tasks, which tools they already used to present data, which types of graphs they commonly used, e.g., line, bar, pie charts, etc., to investigate what abilities do pupils already have to work with data? What skills would be necessary? We also asked about different technologies already used in schools and which visualization tool would be appropriate? How far pupils are familiar with data collection concepts?

Open data impact:

What would be the benefits of open data in teaching? What would be the impact of open data on pupils' learning behavior? What are the teacher's views on using real local area examples in their teaching? What data sets would be interesting for pupils as part of the teaching subjects?

Challenges:

We asked about different problems and challenges concerning bringing open data into schools and suggestions as to how these could be overcome.

To bring open data into schools, some key factors play an important part in using open data as an educational resource. During the survey, these factors are considered to know how teachers understand and could work with these factors. For example, how they can relate simple open data visualization with different subjects and for open data presentation, which visualizations tools and techniques teachers can use. Which types of visualizations are easily understandable by the pupils (line, bar, pie, maps, etc.), or how they can collect live data using sensors or other technologies to give hands in experience to younger students, e.g., physical data using trackers or room's environment using sensors.

The next section describes the key factors chosen for their potential role in developing open data literacy in schools. These key factors are considered in developing the questionnaire to get the best possible feedback from teachers.

4.1 Key factors

The following key factors are discussed during the interviews with teachers to understand their perspectives about open data education in schools. During the interviews, we explained these factors briefly to the teachers so that they were well aware of these topics and their use in real life.

Open Data visualizations:

To explain which type of data sets are available on the city website, we presented data sets within educational themes discussed in Section 3, e.g., data about population, city division, and socio-economic data. These data sets are big and are in different formats, e.g., GeoJSON and SHP and it was difficult for the teachers to understand these. We, therefore, transformed these data sets into CSV and XLS formats and also split the bigger data sets into smaller data sets containing the information about the local areas of respective schools. In this way, it became easier for the teachers to understand the information. We then asked the teachers about their perspective on the use of open data sets as part of science, mathematics, or geography subjects. Their feedback will be discussed in the next section.

Visualization Techniques:

The data itself has little meaning without representation. The Danish public schools already used different tools for the representation of data. Some of them are:

- GeoGebra
- Microsoft Excel
- WordMat

To work with open data, it is important to use software that is compatible with big data sets, easy to access, user-friendly, and provides free licensing for schools. We visualize open data sets using different visualization software which provides free academic programs for teachers and pupils, e.g., Tableau, QlikView, etc. Figure 5.5 is an example of open data visualization

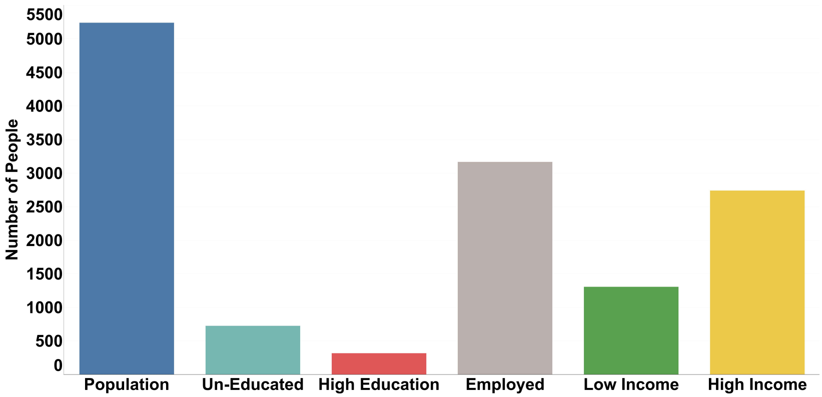

Fig. 5.5: Statistical Details of Sydhavens district of Copenhagen Using Tableau

using Tableau. It represents the statistical details of the Sydhavens district of Copenhagen city. We want to investigate the teachers' views about the complexity of the new tools in comparison with the tools they already used in their teaching. We also asked about the challenges in introducing new technology in the schools.

Sensors and sensor data:

Sensors play an important role in the collection of real-time data. Many data sets from city websites are generated from sensors, e.g., data about traffic, noise level, and light. As part of the Copenhagen Community Drive project, pupils are expected to use sensors for the collection of data to understand and identify different problems of the local areas near the schools, e.g., lack of light, noise level, or similar. We presented examples of environmental sensors to the school teachers shown in Figure 5.6. These sensors are used to measure air quality, temperature, humidity, and similar other parameters and are for indoor use. We also introduce outdoor sensors which can count the number of people passing by a specific path using WiFi devices as shown in Figure 5.6. We described the different functions of sensors and how teachers can use these sensors to measure different parameters. We also showed them the graphs of generated data for different parameters such as humidity, temperature, etc., to help them understand how they can work with sensor technology. We then asked the teachers about their views on pupils' interest in such technology, how useful it might be, and how they might use sensors in their teaching plans.

Fig. 5.6: RuspberryPi and Environmental Sensors

Experienced data and its collection:

The concept of experienced data is also one of the key points in the interview study. In Danish public schools, different data collection methods are already used. These vary from teacher to teacher and grade to grade. These include quantitative, qualitative, and technology-based methods. We asked the teachers about different tasks where pupils collect data with their own experience as part of their studies.

We asked teachers about the research questions, key factors, and pupils' current skills about work with open data and its presentation. The questionnaire consists of structured questions and open-ended questions about open data, its use, its impact, required skills and competencies, and potential challenges. Based on their feedback, key points are formulated which are discussed in the result section.

4.2 Observation

To investigate the best possible impact of open data in schools, we use the observation method with a group of 12 pupils of 7th grade aged around 12-13 years along with their respective science teacher. We use audio and video devices to observe the experiment with pupils' permission. The experiment was one and a half-hour long. The pupils were provided with information about pollution levels near their school area using simple open data visualizations. The teacher first explains the pollution graph and afterward, the pupils were asked to discuss it with each other and explain what they understand or share any useful information from the graph. After the discussion, the pupils pointed out that at some periods of the day the pollution level is higher in the morning and afternoon timings because this is the time when most of the pupils are dropped off and picked up by their parents. We asked pupils how the environment could be improved for the whole day near the school, and they came up with practical solutions, e.g., arrange carpooling if the distance is too large, use bicycles, or switched to walk if possible. This short observation elicits pupils' abilities to understand real data and find the solution to common problems near their areas. The key results from the observation are discussed in the next section.

5 Results

The collected data were analyzed through several steps, i.e., categorized the data using the coding process, filter the teachers' response on each category, interrogate the resulted data corresponding to different categories and finally draw the conclusions. For analyzing the pupils' observation, we closely examine the observation to understand the ways pupils work together and discuss the task corresponding to open data visualization.

According to our survey results, teachers are generally highly positive about the concept of including real data sets in teaching as part of different subjects. They also point out that it will make it relatively easy to relate their subjects to real life and capture pupils' interest. Teaching pupils how to integrate various data sets from the city's open data and produce practical conclusions allows them to develop, build and establish higher-level learning outcomes in their studies. It will also help them to raise critical questions and make conclusions based on the data available about their local environment. Overall, the interviews also illustrate what competencies pupils already have and which skills, need to be acquired to successfully introduce open data in teaching. When we asked one of the teachers about introducing open data in his class, he answered that

"Everything can catch the kids' attention if it is related to their everyday life, and if teachers also think it is fun, then everything is ready to go. You just need to relate what is exciting in the pupils' real world". (Teacher 1, October 23, 2018, 09:42 a.m.)

About introducing visualizations and sensors technology, another teacher answered as

"Pupils can easily accept when it comes to introducing a new tool or technology. They are always excited to work with different and new tools. We just need to learn how to use and grasp these tools". (Teacher 2, October 23, 2018, 15:42 p.m.)

The following are the main key points based on the survey results with school teachers:

5.1 Existing skills and competencies

- 4-6th grade pupils are familiar with small data collections, data arrangements, simple graphical data representations, i.e., curves, columns, and pie charts typically in mathematics.
- In 7th and upper grades the above-mentioned topics are taught at an advanced level. Pupils will work with the analysis of diagrams and findings. They used these concepts in mathematics along with social sciences and food science subjects.
- Commonly pupils work with tables and charts in papers and hand-ins.
- Pupils in 5-7th grade are familiar with Google Maps and the teachers expect that they would be able to solve simple tasks using user-friendly visualizations software. They are already familiar with Excel, GeoGebra, and similar tools.
- Teachers often use real-life examples for pupils, e.g., in statistics where they can observe the class shoe sizes or hair colors.
- Pupils often collect data outside the school environment, e.g., to measure the height of a tower in a park or counting how many cars pass a road.

5.2 Open data impact

- Bringing open data into the schools, as parts of the different subject will develop the pupils' interest and engagement in learning assignments.
- It will become easy for teachers and pupils to relate real facts of their areas and their city, as part of different subjects.

- Open data can help to improve public awareness among pupils, e.g., pupils will be able to understand how they can help to improve the environment or save energy and contribute to sustainable use of resources.
- Open data could support teaching activities in developing pupils' skills to ask questions about different facts related to their subjects as well as their city and local areas.
- Collecting data about their local areas will help pupils to understand the different problems in their area.
- Teachers suggested data sets about population, traffic, pollution, gender, age and similar as interesting examples for pupils.
- Data collection using sensors will give pupils a hands-on experience about how data is generated and how they can use such data for solving a problem.
- Using visualization tools to present open data in schools will create new opportunities for school children to come up with new ideas of understanding their near world and society's problems.

5.3 Challenges

- Teachers have very limited knowledge about open data and visualization tools.
- Most of the open-source visualization tools are in English, it is important to explain some of the frequently used terms in pupils' native language.
- Teachers and pupils are not familiar with data cleaning and preparing concepts.
- Teachers and pupils will need smaller and specific open data sets instead of larger sets to relate their subjects to local conditions, e.g., populations, pollution levels, or traffic within their local areas.

These key points from the teacher's interviews will help us to analyze the teacher's perspective and challenges for open data literacy at schools. Teachers believe that engaging pupils in data exploration will give them a new way to look at e.g., mathematical problem solving and engaging those pupils who do not have an interest in traditional approaches. The experiment with pupils shows that active investigation within their local areas using open data will help build civic awareness among pupils. The interviews also explored the potential of technology to enable out-of-class data collection and new approaches for data learning at schools.

6 Conclusion

In this research paper, we have presented a study of Copenhagen open data, identified educational open data themes corresponding to educational domains and their potential impact on school pupils in the development of their local areas. We interviewed Danish public school teachers and concluded that instead of assuming open data exploration only for adults, we should introduce these concepts to the next generation of learners. By supporting data literacy at schools, we can empower young pupils to become data experts. Open data literate youth will be able to understand which types of data they need for solving a problem in their daily life, and the use of the latest technology for visualization will enable them to explore the city's open data in greater detail and to present it understandably. To face the above-mentioned challenges, teacher training programs or workshops where these new concepts are introduced to them can be helpful. This study will contribute as the first step towards open data literacy at Danish schools and pupils' engagements in understanding different challenges of their local areas.

Chapter 6

Paper 3: Enterprise architecture oriented requirements engineering for the design of a school friendly open data web interface

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This paper (which is an extended version of the conference paper,
Enterprise architecture oriented requirements engineering for open data usage in schools, published in the *18th International Conference on Perspectives in Business Informatics Research; Poland*, pp. 135–147, 2019.)
has been published in the *Complex Systems Informatics and Modeling Quarterly* issue. 21, pp. 1–20, 2019.

Abstract

Open data is considered a key to scientific innovations. These freely available data sets can also be utilized as a foundation to enhance the digital and data literacies among the younger generation of school pupils. This article presents the design and prototype of an open data web interface based on the Enterprise Architecture Oriented Requirements Engineering (EAORE) approach for open data usage as an educational resource in Danish public schools. We first systematically review the literature on open data use in educational fields and selected 14 research articles with a particular focus on the use of open data in the educational domain after prescribing an inclusion/exclusion criteria on 101 research articles identified initially. The review indicates that there is a gap between open data opportunities within the educational domain and in exploring the use of open data as a source to develop twenty-first-century skills, specifically digital and data literacies among younger school pupils. To fill this gap, we propose an EAORE approach that represents how Enterprise Architecture (EA) models can guide the overall Requirements Engineering (RE) process for the use of open data in Danish public schools. Based on these EA models, we designed the prototype of an open data web interface for schools.

Keywords

Enterprise architecture; requirements engineering; open data; open data web interface; educational resource; digital literacy; data literacy.

1 Introduction

The work in this article is an extension of our initial study reported in [61]. As novel contributions, we present (1) a systematic literature review on the use of open data in different educational sectors, (2) a research gap identified in exploring the educational opportunities offered by open data, and (3) the design and prototype of an open data web interface proposed as the result of an Enterprise Architecture Oriented Requirements Engineering (EAORE) process.

Open data is openly available data sets permitting citizens to freely use, modify, and share them for any purpose [96]. Open data is open to everyone, i.e., citizens, businesses, non-profits, public administrations, and technologists. It is a resource that can potentially promote democracy, transparency, civic engagement, efficient public services, and economic growth. Open data opportunities and benefits could significantly increase if citizens were able to use that data effectively and efficiently [8, 107]. Hence, citizens' active engagement is vital to harness the power of open data. However, open data discussions and research typically focus more on the technical side, e.g., collection, storage, availability, and licensing, and have largely neglected issues related to the public and its consequent use by citizens [16, 92]. These issues include such questions as which data sets the public needs, how open data can be used as an educational resource, and how citizens can be engaged in exploiting available open data. We believe that it is important to engage younger school pupils with open data to equip future generations with essential learning skills. Open data can act as a key to develop twenty-first-century skills such as enhancing critical thinking, digital and data literacy skills and civic awareness among pupils [28]. Hence, open data is not only a potential resource of opportunities for the public (e.g., to improve public services, to bring greater transparency, etc.); it could also act as twenty-first-century raw material to develop digital and data skills among public school pupils, as well as a source to inform them about their communities. However, the educational use of these openly available data sets is so far very limited - particularly in schools to facilitate teaching activities using open data as part of different subjects.

Many open data sets that could be used as part of teaching materials are available on various countries' open data portals. Public schools could experiment with these openly available data sets to grow public engagement and to develop digital and data skills, as well as to foster civic awareness among younger pupils. For instance, as part of a chemistry class, pollution levels, noise levels, and water quality data sets can provide up-to-date knowledge about local areas. Pupils can further discuss why the levels are high or low, and how they could work to improve the situation [108]. Open data sets can be used as educational resources to support the teaching of a wide variety of subjects and to permit pupils to work with the actual data sets to develop new learning skills. Hence, several countries have started taking initiatives and launching different projects to introduce the possible opportunities of open data [109] to the younger generation of pupils. The work reported in this article is part of the Copenhagen Community Drive project [110] that particularly focuses on the city's many types of data and how to put them into use, primarily in an educational context. The project focuses on how and to what extent existing open data can facilitate the educational process in Danish public schools, and how we can integrate open data and associated technologies in schools in a way that benefits pupils' digital and learning skills.

To facilitate educational activities using different forms of data Alper et al. [70] recommends that appropriate data sets should be visualized in simple graphs, e.g., bar, pie, or line graphs. The availability of interesting data sets through open data could allow both, teachers and pupils to develop data literacy skills. However, even such relatively simple use of data requires considerable effort by teachers, and they may need data analytic skills, e.g., to fragment the bigger data sets into smaller data sets and make visualizations. We propose to develop an open data web interface that can facilitate public schools to stimulate open data usage in elementary schools by allowing teachers and pupils to relate their subjects to the actual information of their local areas and compare the data with that of other communities in the form of simple visualizations. However, for the development of such an interface, it is essential to identify the requirements of teachers and pupils. To the best of our knowledge, there exist no guidelines for the requirements engineering process for the usage of open data in schools as an educational resource. This article makes a step towards defining best practices for such situations using principles of Requirements Engineering (RE) within an Enterprise Architecture (EA) framework. We start from the following research question:

"How can enterprise architecture guide the requirements engineering process to establish needs and requirements of teachers and pupils to stimulating the use of open data as an educational resource in Danish public schools?"

We believe that the obtained results are sufficiently general and might be interesting for other researchers working in the domain of open data applications. We use EA models to help elicit requirements for the development of the open data web interface for schools using the EAORE approach. The interface could enable teachers to relate their subjects to actual open data, e.g., pollution level, noise level, or traffic congestion near the schools. In this work, RE and EA have been integrated to investigate the problem, specify solutions, and validate the solutions for the development of an open data web interface that allows teachers to use open data as an educational resource at public schools.

The structure of the article is as follows: In Section 2, we present a systematic literature review on the use of open data in the educational domain. In Section 3, we discuss the research methods and related work regarding requirements identification. In Section 4, we outline our proposal for an Enterprise Architecture Oriented Requirements Engineering (EAORE) approach in the context of open data usage in schools along with the design of the open data web interface in Section 5. We provide a brief conclusion in Section 6.

2 Literature review

In recent years, open data has gained massive attention, and many countries have started publishing data that is open for the public [111]. The use of these real data sets is nonetheless generally limited to government, business, and research institutes. Many researchers have taken initiatives to investigate how these real data sets could be used in domains other than industry and government. Moreover, literature exists within the research community that explores different factors that influence the use of open data by citizens [62]. There have been many systematic literature reviews on the technical side of open data, and topics include the usage of open government data [112], open data initiatives [113], publishing of open data [114], and classification, perspectives, benefits, and barriers of open data [115]. However, the possibilities and opportunities for open data usage in the domain of education have largely been overlooked. Among few types of research within this domain, Atenas et al. [16] discussed the use of open data as educational resources in higher education. The authors used case studies to explore the utilization of open data as a form of educational resource with higher education students. The authors discussed different ways that open data could help to develop transversal skills among students.

In this article we claim that these real data sets can also facilitate educational activities of younger school-children specifically, pupils from fifth grade and onward (mostly pupils start working with different forms of data from grade fifth and above). As a research contribution, we present a systematic review of the educational use of open data in education.

2.1 Review methods

A systematic mapping review method [116,117] was applied to map and classify the research literature to identify any gaps for the research community (see Figure 6.1). The design of the literature review consists of a careful collection of research articles, analysis of these articles, and a systematic mapping of the findings. The review considers only research papers about open data usage in teaching, learning, and developing skills among younger pupils. The literature is discussed in four broad categories: (1) the motivation for using open data as an educational resource, (2) the use of open data in higher education, (3) the use of open data in elementary education, and (4) the use of open data in developing educational tools to assist different teaching activities. The objective of the review is to present a comprehensive overview of relevant academic literature on these four categories and to identify gaps for future research. For this, we identify different forms of the use of open data in educational settings, including the development of tools and technologies based on open data in the educational domain.

Collection of research articles

We utilized the following search engines for data collection:

- Scopus
- ACM Digital Library

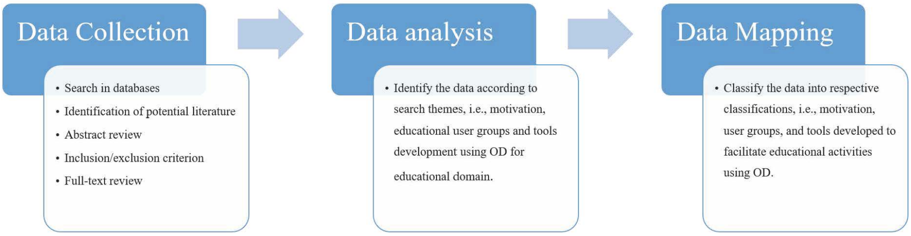

Fig. 6.1: Overview of systematic mapping review method inspired by [117]

- Web of Science
- Google Scholar

The phrases "open data as an educational resource", "open data in schools", "using open data in teaching", "open data and education", "open data usage in schools", and "educational use of open data" were used to search the various databases in the title, abstract, and keywords of the articles.

Selection

To reduce the risk of bias, we implemented clear inclusion and exclusion criteria:

- Only peer-reviewed research articles in English were included.
- Only open data studies were included in which the focus was on the educational domain.
- We only considered studies that focused on one or more of the following dimensions: motivation for using open data as an educational resource, the use of open data in the educational domain, and the development of tools based on open data for educational use.

Table 6.1 represents the overall number of initially identified studies. To avoid duplication, we chose the articles retrieved from the first database (the ACM Digital Library) and then only considered new papers from the rest of the databases. 101 research articles were initially retrieved using the search phrases mentioned above. After the screening of titles, keywords and excluding the articles that were not peer-reviewed, 45 articles were selected for the screening of abstracts. After careful screening of the abstract fourteen research articles were selected for data analysis that fulfills the inclusion and exclusion criteria mentioned above.

To classify the research articles into different categories for analysis, we followed an approach for thematic analysis discussed in [117]. The thematic

Table 6.1: Initial search results for data collection

Search Engines	Initial Search Results	Abstract Screening	Selected Studies
Scopus	39	15	3
ACM	46	21	7
Web of Science	6	4	2
Google Scholar	10	5	2
Total	**101**	**45**	**14**

Table 6.2: Outline of reviewed articles and identified categories

Categories	First Author and Reference	Articles
Motivation	Atenas [16], Tim [13], Manca [118]	3
Open data usage in higher education	Renuka [119], Shamash [120], Love [17] Tim [121], Perez-del-Hoyo [122], Anslow [123]	6
Open data usage in elementary schools	Annika [124], Saddiqa [108], Saddiqa [19]	3
Open data tools for educational use	Dunwell [125], Marie Friberger [51]	2

categories were specified by identifying and mapping the reviewed articles for open data usage within the educational domain.

2.2 Review findings

Table 6.2 shows an overview of the papers included in the review and classified into the four categories discussed above.

Motivation for using open data

Open data has many aspects that could benefit the educational domain, for instance, the internal element, the scientific side, and its power to bring transparency and accountability. In connection with the educational use, the inner and scientific aspects act as elements for the motivation of open data usage in education [28]. For instance, the subjective element allows pupils to learn and solve problems and to understand their real world. With the scientific element of open data, pupils and teachers could re-use this data to develop knowledge in other educational fields. However, the limited research to date on open data usage in teaching suggests a lack of awareness among educators. There is little research on why or how open data should be employed in teaching practices.

[16] explores the fundamental ways to support educators in empowering pupils with essential twenty-first-century skills. The study investigated how

the use of open data can be a key to the development of transversal skills, including digital and data literacy. [13] investigated the value and challenges of using open data in education through the vision of early adopters of open data. The author presents a qualitative descriptive design to understand the perspective of open data usage in teaching through interviews. By working with early adopters, the author identifies that open data has potential as authentic and relevant material that expands the possibilities for learning activities. The study further identified that learners and educators lacked data literacy or resources to make full use of open data opportunities. Manca et al. [118] discussed another aspect of open data when used as an open educational resource. According to this study, open data can act as a powerful resource for learners in the context of post-traumatic societies when supported by a critical pedagogy scaffolding.

Open data usage in higher education

The review reveals that most users of open data in educational domains were higher education students. The students typically use open data in their research projects or assignments to develop digital and data skills. [119] investigates how undergraduate students could benefit from the vast amount of data in different fields. The study aimed to engage the student community with the data to increase their affective domain learning, and make them realize the vast potential that raw data holds for them. The results showed that suggesting and introducing the concepts of research and harnessing the massive amount of open data enabled them to produce useful results for society. [120] describes experiences of a case study in how a group of master's degree students determined the importance and limitations of working with numerical data. The students picked a data set and an API of their own choice (Twitter, VPL, Biblioshare, CrossRef, etc.), combined them using Google Refine, and cleaned and manipulated the data for analysis. The case study highlighted the importance of using openly available data in the classroom, and how the use of open data motivates the students to share their observations and outcomes. In [17], the authors describe an assignment examining the correlation between climate conditions and levels of air pollution. The case study demonstrates key elements of accessing relevant open data and the use of data mining techniques. A similar study [121] reports results from a case study that explores why and how open data can be used as material to produce engaging challenges for students when they are introduced to programming. By describing the method of developing the assignments, the author suggests that open data is robust material for creating educational activities because of its ease of use and authenticity. [122] discusses the experiences from the University of Alicante (UA). The experiment involved introducing students to a smart consumption of information along with its analysis and interpretation. The study indicated that the opportunity to operate with freely accessible, large geo-referenced databases represents an excellent potential for research and instruction in engineering education. [123] emphasizes the need to increase the data literacy of computer science students. To address the needs of student data science and analytic skills, the authors proposed augmenting the existing data science curriculum with 'hackathon type' events (where a large number of people gather to participate in collaborative computer science events) that focus on data, also known as 'datathons'. The authors shared their experiences of organizing four datathons, which engaged students and community members to solve complex problems using open data and data from non-profit social welfare organizations. The authors suggest that with the increase in data amounts, there will be a need for people to learn and increase their skills with key data science and analytic techniques and tools to make better-informed decisions.

Open data usage in elementary schools

Not much literature within the research community exists focusing on the use of open data in elementary schools.

[124] describes an approach to teaching data skills in schools using real-life, sophisticated urban data sets collected as part of a smart city project. The approach was based on the notion that young pupils can work with data sets if the tasks are relevant to real-life situations and students are properly supported. Descriptive methods were used to design the task and to facilitate interpretation and tell stories from the data. The study participants were twelve pupils aged 9-10 years from a UK primary school. The pupils learned about home energy usage and the production of solar energy from residential solar photovoltaic (PV) technology, by analyzing existing visualizations of smart meter data and data obtained from a survey. Saddiqa et al. [108] presented survey results of open data visualization in Danish public schools. The authors conducted interviews and set up pilot tests to introduce and investigate the scope of open data visualizations in elementary schools for fifth grade and above. The results showed that simple open data visualizations about the pupils' municipalities attracted their attention and encouraged discussions and reflections. Teachers were highly positive, but they needed ready-to-use data sets as part of teaching assignments. Also, for young pupils, the concept of open data was very abstract. To develop data skills, the authors suggested designing different activities for data collection as part of learning assignments. In another study, Saddiqa et al. [19], identified open data domains that could easily facilitate basic school subjects, such as mathematics, science, social science, and geography, and presented example data sets to teachers in interviews and by setting up observations with

a group of pupils attempting to make the use of the data sets. The authors highlighted different challenges in using open data at the school level. Teachers needed extra time or data analytic skills to use these real data sets in their class environments. In addition, most of the visualization tools were available in English only, which was also considered a hurdle for engaging the elementary schools with open data, when the pupils are non-native speakers of English.

Development of open data tools for educational use

In this category, the focus is on research where efforts are made to develop tools and technology based on open data specifically for educational use. [125] describes the approach taken by a serious game to contribute to the development of active lifestyles among youngsters by utilizing open data on nutritional information from the United States Department of Agriculture. The game itself draws the player as a survivor in a post-apocalyptic setting, with the goal of survival and exploration. The results showed how standard game mechanics can be applied to open data to provide useful and engaging educational experiences. The author of [51] contributed in her research to the ever-growing list of things that can be done with games by proposing, discussing, and exemplifying data games. Data games vary from many other forms of serious games in that they do not have a predetermined plan; instead, they are techniques for the player to use to discover data with few constrictions. Such games help to increase the use of open data and linked data because the increasing amount of data available in this manner lends itself to game-based exploration. The author, as an example, describes 'Open Data Monopoly.' With this type of game, pupils can be provided with a means of visualizing publicly available data about their countries and neighborhoods. As web-based open data sources become more available and active, interpreting and reusing this data for educational purposes is becoming a major topic [126]. Although there is limited evidence on the techniques for translating data into educational materials, both pedagogical and technological, games can be an important medium for accomplishing this.

The results of the current review show that the majority of studies of open data usage in education have been conducted with a focus on the use of open data in higher education. The described categories (motivation, open data usage in elementary schools, and open data tools for educational use) need to be explored in more depth in future research. With the advancement in digital technologies and access to real data sets in our communities, it becomes crucial to equip our next generation with essential future skills, mainly in digital and data capabilities. For this, teachers and pupils must be aware of and able to use available open resources that allow them to develop these essential skills. Therefore, in future research to fill this gap, our focus will be on the motivational aspect of open data usage in education to make educators aware of the educational potentials of open data and how open data could benefit elementary public school pupils in developing digital and data literacy. There is also a need for developing open data tools and technologies that could facilitate teaching activities.

3 Research methods and related work regarding requirements

The research approach used to design the approach for requirements identification in the context of open data usage in schools consisted of the following steps:

1. Analyze open data sets of the target domains.
2. Identify open data impact domains that may facilitate teaching.
3. Analyze available data visualization tools.
4. Survey Danish schools to learn teachers' and pupils' perspectives on open data.
5. Envision a possible solution for open data usage in schools.
6. Propose an approach for the identification of requirements for the envisioned solution.

To analyze open data sets of the target domains, we accessed the open data sets through the national open data portal of Denmark[1] where cities, organizations, and researchers publish data that may be useful for the public. This data source is used to develop different mobile applications and improve public services to bring benefits to the citizens of Denmark. To use open data sets as educational resources in Danish public schools, we carefully *analyzed open data sets of the city of Copenhagen*, the capital of Denmark. Copenhagen has more than 290 open data sets from different sources, accessible from the national open data portal of Denmark. These data sets include information of various types, for instance, graphical data, statistical data, and live data, and data is available in different formats (such as CSV, PDF, JSON, etc.).

We identified four impact domains, or educational domains: *environment, demographics, geographical, and statistical data*, that have the potential to easily facilitate teaching as a part of primary public school subjects, such as science, social science, geography, and mathematics. Some *open source data*

[1] `http://www.opendata.dk/`

visualization tools were also analyzed for their possible adoption in visualizing open data. We also *surveyed ten Danish public schools* to understand teacher and student perspectives in open data usage. This work is discussed in [19,108]. Teachers were very positive about the potential to facilitate teaching with actual data, but they required ready-to-use data sets and visualizations as part of teaching assignments. In addition, it was mentioned that the available open-source tools for visualization were not in Danish, which was also considered a hurdle for the presentation of open data at the school level in Denmark. Teachers requested an overview of what data sets were available and pointed to the fact that it requires both the time and skills of teachers to present the relevant information to the pupils. Hence, the development of an *open data web interface* that enables pupils and teachers to select data sets within educational themes and aids in visualizing the data in the form of simple graphs, comparing data between areas, and designing activities to explore more data as part of respective subjects, *could address the above-described issues*. For the development of the open data interface for schools and to identify teachers' and pupils' requirements, we used Requirements Engineering (RE), which is an approach to investigate, define, document, and maintain the requirements for the best-desired solution. RE is not principally about just documenting requirements; instead, it focuses on understanding a business problem and providing a solution for it [127, 128]. The RE discipline has expanded over the last decade, and the process includes not only traditional techniques, such as interviews, surveys, and workshops [129] or viewpoint-oriented RE [130]. It has also inspired several new methods and models, for instance, GBRAM (goal-based requirement analysis method) [131], i* [132], and KAOS (knowledge acquisition in automated specification) [133]. There are two different main views on RE: problem-oriented, and solution-oriented RE [134,135]. "Problem-oriented RE focuses more on investigating and documenting a problem domain. The requirements engineer identifies the different factors (reasons) for the problem, the relations between these factors, why this is seen as a problem, and who experiences these problems". "Goal-Oriented RE (GORE) is a prevalent and widely used technique within problem-oriented RE. Goals are considered as high-level objectives of the system, business, or organization that identify the reasons for the development of a system and help to make decisions at different levels within an enterprise" [136]. VanLamsweerde [137] gives a general description of GORE; which is also used as part of the GBRAM and KAOS models. Solution-oriented RE, on the other hand, uses traditional techniques for software engineering, in other words, object-oriented analysis [138] and structured analysis [139]. The requirements specification for a solution represents the system from the software engineers' perspective [140] (e.g., system specification, system functions, quality attributes of these functions) and defines the alternatives for the best solution of the problem. Hence, the generic

RE process consists of the following functions:

- Requirements Elicitation
- Requirements Analysis
- Requirements Specification
- Requirements Validation

Within the RE domain, research is done in almost every field of business (such as transport, education, health care, etc.), but to the best of our knowledge, no work has been done within the development of requirements models for open data usage in schools. Enterprise Architecture (EA) on the other hand, is the complete, consistent, and coherent set of methods, rules, models, and tools that guide the design, migration, implementation, and governance of business processes, organizational structures, information systems, and the technical infrastructure of an organization according to [141, 142]. EA is the practice of analyzing, designing, planning, and implementing enterprise analysis to execute business strategies successfully. We choose to combine RE with EA [143] as EA can have a significant impact on the requirements engineering process [144]. In this article, we derived requirements of school teachers and pupils within an EA frame and we proposed a combined Enterprise Architecture Requirements Engineering (EAORE) approach that allows us to identify requirements within different layers of an EA framework. For

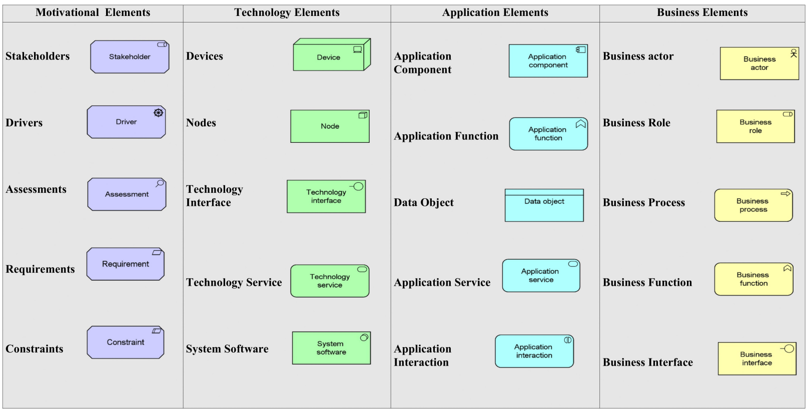

Fig. 6.2: Selected set of elements from ArchiMate

the representation of EA issues, we used a selected set of elements of the EA representation language ArchiMate [145, 146] shown in Figure 6.2 and for modeling, we used the Archi modeling tool [147].

In our study, to derive the enterprise architecture models, the requirements were identified through interviews with Danish public-school teachers, pilot tests, and observations with pupils, where the setup and participant details are given in [19,108]. Using EAORE, we explored and investigated the requirements of the open data interface for schools. To design the EA models in the EAORE approach, we used a four-layer enterprise architecture frame as shown in Figure 6.3. The models are discussed in the next section.

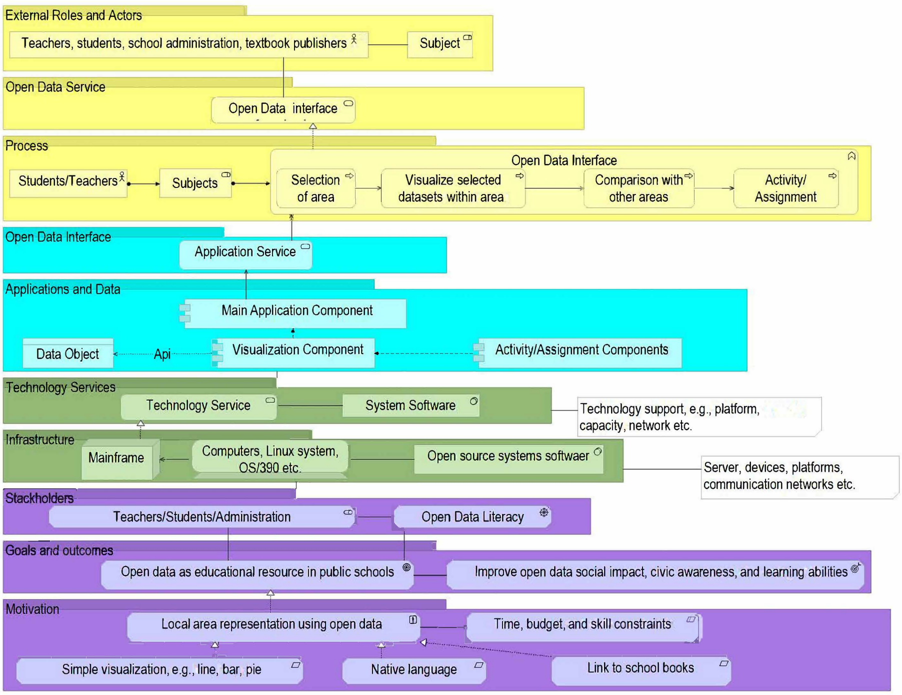

Fig. 6.3: Layered view of EA for open data usage in schools

4 Enterprise architecture models in RE for open data usage in schools

Using EAORE, we developed a four-layer EA frame using the ArchiMate language, as shown in Figure 6.3. Our EA frame for open data usage in schools represents the motivational business, application, technology, and motivation layers. The sets of (related) EA element types serve as a frame of reference that guides the RE in each layer. We investigated requirements in each layer concerning different possible aspects shown in Figure 6.3. This layered view allows us to illustrate the motivation for the interface, potential concerns and assessments, technology requirements, and the usage of applications in business processes and the services they provide. In the remainder of this section, we will discuss the possible requirements, needs, and goals for each layer shown in Figure 6.3.

4.1 Motivation layer

On the motivation layer, we have explored the stakeholders; their needs, concerns, and assessments; and how they interact with the system (open data interface). It also includes the motivational aspects (e.g., why teachers might use open data) and domain knowledge. The resulting models are shown in Figure 6.4 and Figure 6.5.

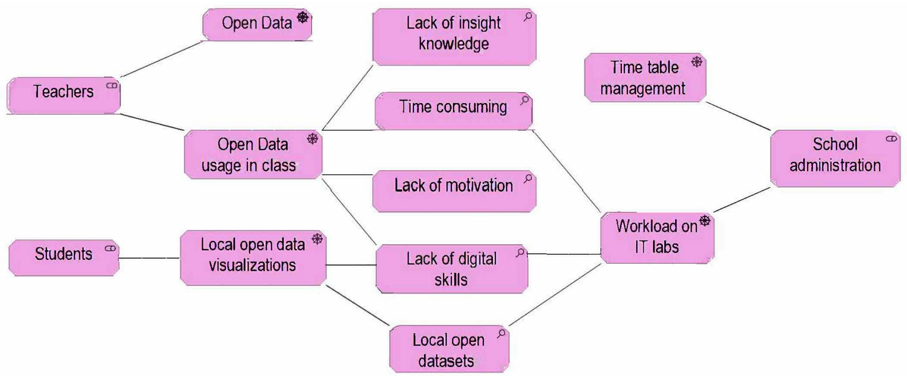

Fig. 6.4: Stakeholder, concerns and assessments

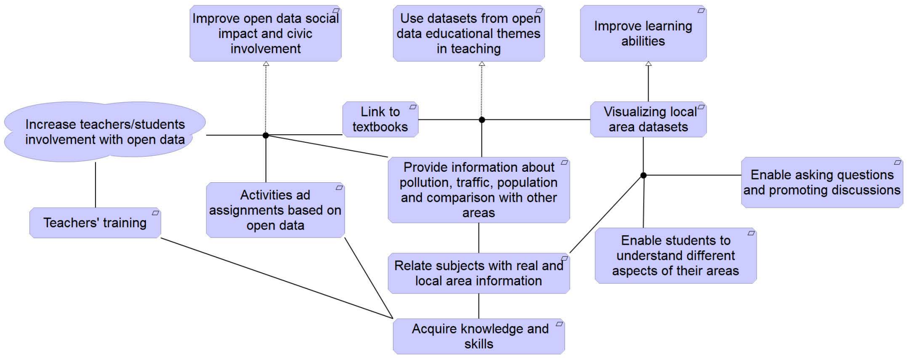

Fig. 6.5: Motivational layer requirements model

Figure 6.5 represents the RE issues for the needs and concerns shown in

Figure 6.4. In our case, we have identified three main internal stakeholders, namely, teachers, pupils, and the school administration, as well as textbook publishers as external stakeholders. Teachers are concerned with different data types, their graphs, the cleaning of data sets, and the transformations of data into other formats. Pupils need simple interactive charts in their native language. Teachers are reluctant to spend a long time searching data sets. These identified concerns from the pupils and teachers can provide examples of important assessment criteria. For instance, there exist many open data sets with useful information that are not being exploited. These data sets can easily be used as free educational resources that can relate actual details to the study subjects to develop learning skills discussed in the previous sections. This would lead to the high-level goal to "increase open data social impact and youth engagement with open data." Teachers and pupils are not able to work directly with open data as they need simple presentations of open data sets in their native language. This can be a problem, as teachers are hesitant to spend a long time identifying and visualizing the data sets, and the available open-source software for visualization is not available in their native language. Through goal refinement, we reached the goals that we want to introduce an open data interface that allows pupils and teachers to relate to their subjects with actual information using open data as an educational resource and to improve civic awareness and youth engagement with open data.

4.2 Technology layer

On the technology layer, we explored what technology requirements are needed from the user and system perspectives. For instance, pupils and teachers must have easy access to computer labs, the internet, etc. Green elements in Figure 6.6 represent a technology layer model for open data usage in schools from the system perspective. For the open data web interface, open

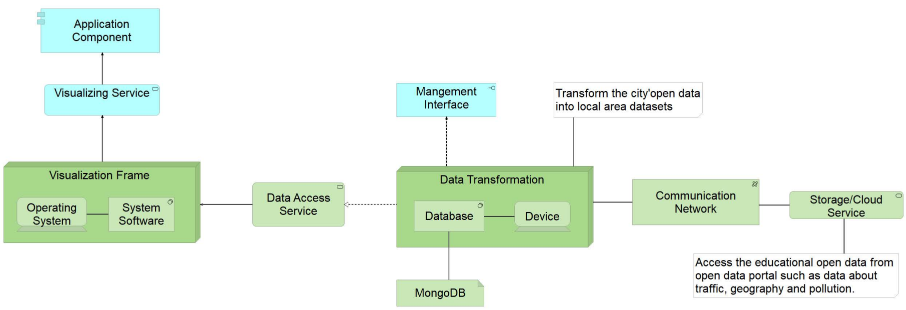

Fig. 6.6: Technology layer requirements model

data sets within the educational domains are needed, such as data sets about pollution, geography, traffic, and population. These data sets are available in different formats through the city's open data portals, such as CSV files, PDF files, or other forms. The relevant open data within the educational themes can be accessed through open data portals and stored in cloud service. The open educational data sets are further transformed into local area data sets and stored in a database such as MongoDB, to visualize the local area information through the open data web interface. These open educational data sets are managed through a management interface. Open-source operating systems and visualization software are required to visualize the open data sets within the educational themes. Based on this technology layer model, prototypes for the open data web interface will be developed and tested before the validation of the final interface in schools.

4.3 Application layer

Figure 6.7 represents an application-layer EA model for open data usage in schools. The application layer focuses on application components. It depends on requirements about language, appearance, and ease of use. The RE for

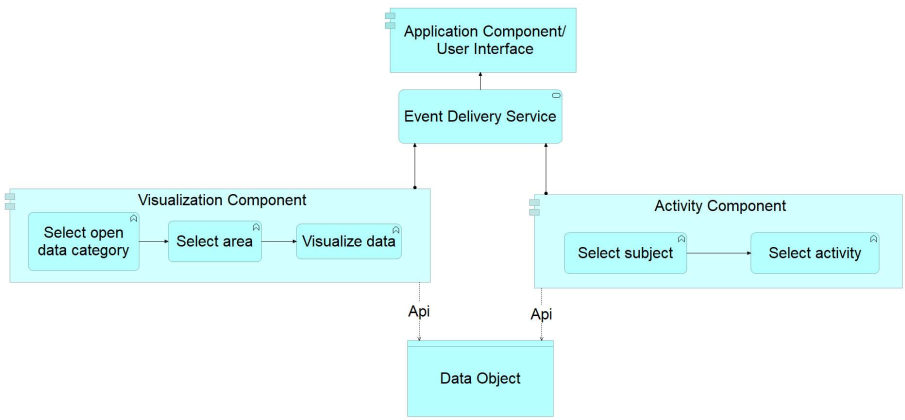

Fig. 6.7: Application layer requirements model

this layer leads to the development of one main component and three subcomponents, in other words, the data object, visualization component, and activity component. Teachers need local area open data sets in the form of simple visualizations (line, pie, bar) in their native language (Danish) to relate their subjects with actual information. The application should be easy to use without any programming expertise and with explained features.

4.4 Business layer

The business layer leads towards the solution, in other words, an open data interface for the schools that enables teachers and pupils to benefit from the data sets. Figure 6.8 represents a usage view (model) for the open data interface, and Figure 6.9 represents the business model for the open data interface. In the business layer, textbook publishers are identified as external actors.

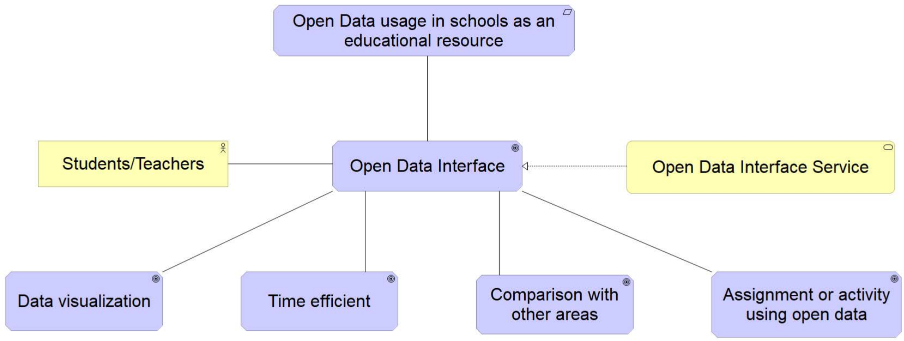

Fig. 6.8: Open data web interface usage view

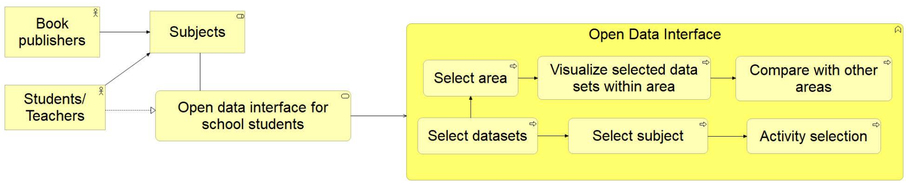

Fig. 6.9: Open data web interface for open data usage in schools (business layer view)

They will play a central role in the active use of this interface. By linking different subject themes with the open data interface for activities and explanations, for instance, in geographic subjects, they can link the interface for the presentation of the respective local areas; or in science classes real, local examples could provide information about pollution, noise, or other environmental conditions. Such subjects as mathematics, science, geography, and social science act as business roles, as these subjects can use open data for visual presentation of local area aspects to facilitate educational activities at the school level.

4.5 Evaluation of EAORE

In the above sub-sections, we have presented models based on the EAORE approach for open data usage in schools. We have discussed the four layers that form the base for our frame and identified requirements in different aspects within these layers. The EAORE approach for open data usage in schools is flexible and could be used by other countries to extend the potentials of open data at the school level as an educational resource. By using EAORE, we covered the motivational, application, technical, and business aspects that enabled us to make a transparent alignment among all these aspects. Using this approach, we derived precise requirements at different layers that are aligned with each other in the form of models. These models will help us to ensure that the need for open data usage will be met in an efficient, sustainable, and adaptable manner. Using the EAORE approach, we can easily trace and change requirements at different stages of the development of the open data web interface. We can also save time, for instance, we can identify requirements at different layers and change or validate them easily at any layer using less time rather than comparing descriptions in text documents. The approach is easy to adopt, and in the future when we extend our research work (with more cases), we will also consider a requirements management system based on this approach. Currently, this article represents only a case-specific model; we will elaborate on EA models and develop an analysis mechanism for more formal EA analysis in future work. It has to be noted that there are many relationships between elements of different layers of the frame. However, we showed only some of them to keep the discussion as simple as possible.

5 Open data web interface (prototype) for Danish public schools

In this section, we describe the design for the open data web interface (reflected by its prototype) according to the identified requirements through our EAORE approach. The aim of developing the open data web interface is to link the open data educational themes with textbooks, as there exists no resource that provides real information of respective cities and municipalities to the young school pupils in the form of simple visuals and graphs. This interface will provide exciting information about cities as part of teaching subjects, for instance, information about the population as part of the geography subject. Different activities within the subject domains are designed to engage pupils actively and to provide hands-on experience. For instance, this could include the collection of data using a notebook and comparing it with existing data through the web interface. Moreover, it also provides an opportunity for teachers to share their experiences with other teachers in the community in the form of blogs. Figure 6.10 shows an overview of the interface (displayed in English for this article). The main page has navigation to cities, activities, and uploading blogs related to open data usage in schools.

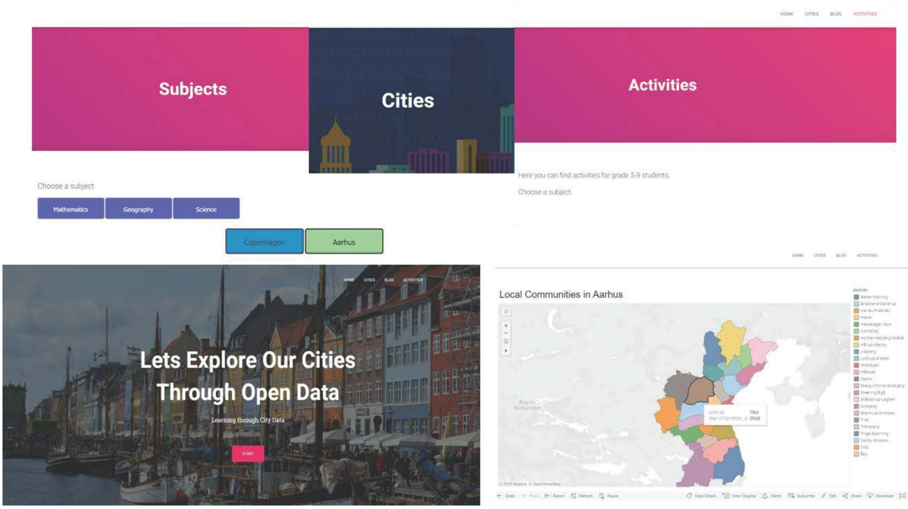

Fig. 6.10: Open data web interface

5.1 Design goals and the prototype

Relationship between open data visualizations and subjects

The main goal is to provide respective information of cities as part of teaching subjects. We have identified four educational open data themes corresponding to basic teaching subjects [19] in public schools: science, mathematics, social sciences, and geography. For instance, the web interface provides current information about pollution levels as part of the science subject.

Access to open data sets of different cities

The web interface also allows pupils and teachers to explore interesting information about other cities and municipalities. Currently, the interface provides access to two bigger cities of Denmark, Copenhagen, and Aarhus, but can also be extended to other cities. Different views of the interface are shown in Figure 6.10.

Simple and interactive visualizations

The web interface provides complex and interesting information in the form of simple interactive graphs and visualizations. We used the Tableau software[2] to visualize the data and integrate it with the web interface. This feature provides an opportunity for pupils and teachers to edit, share, download, and re-draw the graphs.

Activities according to grade level

In the activity component (see Figure 6.10), activities were designed for pupils according to their class level (e.g., from fifth to ninth grade). For instance, fifth-grade pupils used the visualizations as a source of information, while pupils in the sixth grade not only interpreted the visualizations but could also answer some questions related to the visualizations.

Native language

The interface uses the Danish language, so pupils and teachers in Danish public schools can easily interact and understand the provided information.

Interface architecture

The open data web interface was developed with the idea of using open-source tools and software that would allow school teachers and pupils to develop twenty-first-century learning skills. Tableau is used as a visualization tool as it provided free academic licenses for both pupils and teachers. Public schools can easily adapt it for data visualization purposes as an extra side tool. The architecture includes:

- Apache/2.4.41 (Win64)
- OpenSSL/1.1.1c
- PHP/7.3.9
- MySQL (database)
- Tableau (visualization software)

The Tableau software is used to visualize the open data sets. The data sets are saved in a MySQL database after cleaning. Users can use different user-friendly features of Tableau to edit or modify the visuals and can also download the data.

In this section, we have presented the open data web interface that will allow teachers and pupils to interact actively and easily with real information on their cities as part of teaching subjects. The intention is that teachers do not need any additional skills or time to work with open data as part of their teaching assignments. However, the prototype will be further tested in schools regarding these features.

[2] https://www.tableau.com/

6 Conclusion

As society becomes increasingly digitized, it becomes essential to equip our future generations with digital and data skills to confront future challenges. Open data is a valuable resource with potential possibilities for both governments and the public. Thus these openly available data sets could be used as raw material to develop twenty-first-century learning skills. These data sets can be used as an educational resource to support teaching and learning activities as part of teaching subjects, for instance, mathematics, science, and geography. However, in general, teachers and educators are not well aware of these open data sets and associated opportunities as educational resources. The designed open data web interface works as a bridge between the educational potential of open data and its use by the pupils as part of teaching subjects.

In this article, we have provided a systematic literature review on open data usage in the education domain and presented the design and a prototype for an open data web interface based on the EAORE approach. We investigated the teacher and student needs and requirements to stimulate the use of open data as an educational resource in Danish public schools. We proposed and used the EAORE approach and framework for *EA oriented RE for open data usage in Schools*. The use of EA models helped to identify the requirements regarding different aspects such as motivation, technology, application, and solution aspects. Our EAORE approach has several potential advantages: time-saving, easiness of traceability, and flexibility of modeling, as discussed in Section 4. The *open data web interface* will allow both pupils and teachers to experiment with these data sets as part of their everyday learning and to take benefits from the possible potentials of open data as educational material.

Open data has also another important aspect, i.e., economic benefits as discussed in [8]. With the use of open data at the school level, we could also have a positive influence on this aspect. Teachers will have easy access to relevant real information and pupils or students may make better decisions in solving their real-world problems. In the future, we are also interested in addressing some economic benefits deriving from open data usage in schools. For instance, during the testing phase of the open data web interface, we will also analyze how students could identify local area problems and create proposals for solving those problems, such as how they could contribute to reducing the energy use in schools and thus reducing the climate impact. This can potentially affect civic awareness and have economic effects (by reducing energy expenditure).

In the future, we will elaborate on the approach discussed in this article after testing it with more cases and also will use it for designing a requirements management system. To further validate the open data web interface solution, we will test its different parts in schools. This phase will help us to explore and identify new problems based on the proposed solutions. Based on these new problems, revised prototypes will lead us towards the final development of the interface. The interface will not only provide original and interesting information about cities and local municipalities but will also help to develop learning and digital skills and bring more awareness among the younger generation of school pupils about their communities and cities.

7 Acknowledgment

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Chapter 7

Paper 4: Open data interface (ODI) for secondary school education

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Abstract

Advancements in data technology provide easy access to open data sets that can act as raw material to promote data competencies in the education domain. In this study, we investigate how open data can be used to develop digital and data literacy skills among secondary school students (ages 11–15). Using qualitative and quantitative research methods, we identify how data collection and analysis can be integrated into school education using openly available data sets. We also test the usability of a platform for secondary schools that allows teachers to identify and use open data sets when teaching school subjects such as math, science, and geography. The results suggest that open data have the potential to advance the digital and data skills essential for future generations, as well as enable them to understand their surroundings by using real data sets as part of their subjects. The results also demonstrate that the Open Data Interface helps educators utilize open educational data sets in schools.

keywords

Secondary education; digital and data skills; improving classroom teaching; human-computer interface; usability assessment.

1 Introduction

Through technological advancement and data availability, governments worldwide have launched open data portals, providing useful information e.g., about citizens, businesses, education, the environment, infrastructure [148, 149], etc. For example, Denmark has a national open data portal[1], that provides free access to data sets published by government departments and institutions. Similarly, the European open data portal[2], provides access to open data published by EU institutions and bodies. All the data available in these portals are free to use and reuse for commercial or non-commercial purposes, i.e., citizens can freely use and share these data sets for any purpose [150,151].

Open data also have the potential to be used in learning activities [28,50]. Open data can function as a valuable source to educate students about the concept of data by providing them real information e.g., about pollution, traffic, and population conditions of their own neighborhoods and cities. By integrating these real data sets into school subjects, students would not only learn the data concept, but also develop data skills, such as collecting, analyzing, and interpreting data, as well as enhancing digital skills [13].

[1] http://www.opendata.dk/

[2] https://data.europa.eu/euodp/en/data

However, several challenges need to be resolved before open data can be integrated into education and their benefits reaped in the educational realm. The availability of open data in itself is not sufficient for it to become a source of innovation in education. It is also important that users understand what kinds of perspectives open data unlock, and what potential uses are facilitated [30,152]. For instance, teachers lack information about openly available data sets and their potential use in education. Teachers with little expertise in data analytics require extra time and effort, e.g., to identify and visualize data sets as part of their subjects. Thus, strategies are needed to govern open data use in education by addressing these challenges [22,109].

Researchers have discussed various possible uses of open data in education, in which students may acquire data analytics skills. For instance, [120] discusses different ways of examining open data sets through visualization or acquiring data analytics skills by investigating and analyzing open data sets as an integrated part of social science education. However, the literature review presented in [153] indicates that open data is mostly used by students in higher education and that a gap exists between open data use in education, particularly in public schools, and the educational prospects and potential innovation offered by open data. The gap exists due to a lack of awareness about the use of open data in educational settings, as well as the fact that open data portals do not provide direct access to educationally relevant open data sets. [19] investigated how to reduce this gap through interviews, pilot tests, and surveys with teachers and students ages 11–15. The studies indicated that for facilitating open data use in schools, a platform is needed that allows teachers to access suitable open data sets for educational purposes.

In this article, we identify the data skills that can be enhanced and developed using open data and test the usability of an Open Data Interface (ODI) platform prototype developed by [153] that helps teachers use open data in education with real-life scenarios. We investigate the following research questions:

1. What are the main challenges and data skills associated with integrating open data into secondary school education?

2. How can a learning platform be designed to address problems and assist teachers in the use of open data in secondary school?

The study is part of the Community Drive project[3] research project with the focus of understanding how to educate young people to participate in the transition of cities with data-driven methods. The project focuses on the city's many types of data and how to put them into use - especially in an educational context. In the remainder of this paper, we refer to secondary school

[3] https://www.communitydrive.aau.dk/

students ages 11–15 as 'students' and the Open Data Interface prototype as the 'ODI'. Our main contributions in this research article are:

1. Identification of data skills associated with open data in education
2. Identification of challenges for using open data in education
3. Evaluation of the ODI's usability in secondary schools

The article is structured as follows: Section 2 presents the background of open data use in education. In Section 3, we describe the research methods and test setups used. In Section 4, the results are presented, while Section 5 concludes the paper.

2 Background

Open data has the potential to cultivate transparency and scientific innovation [10,151,154]. With the availability of openly accessible data sets, students can work with real data sets, e.g., about their city or neighborhood, grasp facts, and understand real-life problems at a local level. To discuss both the ODI's usability and the use of open data in education, the background section is divided into two subsections: open data in schools and technologies for open data in education.

2.1 Open data in schools

Digital and data literacy are important issues in the development of 21st-century learning skills, which are essential to interact with a digital society that entails the generation of huge amounts of data daily [155, 156]. Thus, it becomes crucial to equip the younger generation with skills so they can interact with data to understand environmental, statistical, and geographical issues relevant to their surroundings. Many aspects of open data merit examining how it can be used in education, e.g., students might be motivated personally at the prospect of learning more about their own neighborhoods.

[16] examined fundamental ways to help educators empower students with essential 21st-century skills. The study presents the findings of an exploratory survey conducted with academics on how they used or incorporated open data such as archaeology data, medical data, city data, statistical data, etc., into their teaching practices to develop transversal skills, including digital and data literacy among students. The *Data Education in Schools* project, funded by the Scottish Government [157], has a particular focus on teaching data literacy and data citizenship skills to learners, developed an interdisciplinary data education curriculum and real-world data

science teaching materials in collaboration with educational researchers, professional learning, and digital skills consultants for primary and secondary school teachers.

The literature indicates that generally, teachers view open data as positive influences on their learning environments [18, 35, 118, 158]. However, many challenges are involved in integrating open data in education, especially in elementary and secondary school education. The limited research to date on the use of open data in education suggests a lack of awareness of its potential among educators according to [13, 17]. The studies indicate that learners and educators lack data literacy (e.g., the knowledge and skills needed to analyze and work with data), as well as resources to make full use of open data opportunities.

[18] list barriers that could influence the use of open data in education, e.g., lack of technical expertise, teachers' lack of understanding of open data, and how to integrate open data sets in school subjects. Both [33] and [34] list factors that hinder open data integration into schools, such as lack of teacher training and challenges in adapting existing data (as most open data sets come from professional environments such as scientific research or public service administration), and that students and teachers may not have the literacy or resources to take benefit of them.

[153] reveals a lack of research on open data use in education, particularly in schools, in terms of how to integrate open data in teaching practices. The study reveals challenges that hinder teachers' efforts to use open data in education, e.g., that the concept of open data itself was found to be too abstract and difficult for students to understand. They need hands-on experience with data collection to understand the data concept and how to use open data. The results of the study reported in [108] indicated that simple open data visualizations representing students' municipalities captured their attention and encouraged discussions and reflections. These include topics such as population, pollution, geographical overview, traffic flow, etc. Open data domains that easily could facilitate basic school subjects – such as mathematics, science, social science, and geography – were identified and discussed in [19]. The study also indicated a need for an interface tailored to educational purposes, i.e., an interface that allows teachers to link their subjects with open data sets suitable for educational purposes.

2.2 Technologies for open data in education

Open data can be viewed as a resource that can advance public services, induce transparency in government policies, and can also advance the educational management [111, 159]. These data sets can also be integrated within educational domains to develop 21st-century learning abilities such as data and digital skills among students.

Several researchers have experimented with different digital platforms to facilitate and provide easy access to open data in higher education. For instance, [51] describes a game called Open Data Monopoly, in which students are provided with the means to visualize publicly available data about their countries and neighborhoods. [125] developed a game that supports the development of healthy lifestyles among adolescents using the U.S. Department of Agriculture's open data portal. The results demonstrated how standard game mechanics could be applied to open data to provide useful and engaging educational experiences. [52] discussed a card game designed to teach environmental matters to early elementary school students using open data. The study shows how the game based on real data sets can gain students' interest in the subject and improve their performance and engagement to the course as compared to conventional teaching.

Despite the rapid development of open data platforms, the accessibility and ease of use of data portals are low and the usability of open data sets available on government platforms presents challenges for citizens, teachers, and students [108, 160]. [161, 162] showed in their research that mostly the open data programs focus on data quality and organization and give less attention to platforms, their use, and impact. This fact restricted citizens, civil society institutions, and educational domains from utilizing open data for their goals. For instance, from an educational perspective, these data sets are often large, and teachers might need to devote much time and effort to identify simple information that can be included readily as part of lesson plans. Most teachers and students are not familiar with the process of data cleaning, i.e., removing irrelevant data from a data set, or with different forms of data structures.

The existing platform such as TuvaLabs[4] and Discover Kells[5] provide the opportunity for improving data analytical skills and present history and education topics in a user-friendly feature respectively. However, to integrate open data into schools, research is needed to investigate how existing open data platforms can be utilized in education, and how educational open data platforms can be designed to facilitate teaching.

There exists a need for an educational interface for schools that allows teachers and students to access education-specific open data sets, rather than spend time searching for relevant educational data sets through, e.g., national open data portals [19]. Requirement models for such an interface were defined in [61]. Based on these requirements, an ODI prototype was developed and presented in [153]. Available at `https://odw.aau.dk/`, the ODI allows teachers to select real data sets from their cities as part of school subjects, i.e., teachers can relate their subjects to actual data, e.g., pollution levels, noise

[4]`https://tuvalabs.com/`

[5]`https://data.gov.ie/showcase/discover-kells`

levels, or traffic congestion near their schools. The interface is open source[6], apart from the visualization tool Tableau.

In this paper, we report on open data use in schools in a real environment using the ODI and reflect on diverse ways of using open data sets in education, their influence on learning-activity behavior, and the usability of the ODI in schools.

3 Research methods

We used a variety of methods and approaches to investigate the research question and evaluate the potential of open data as an educational resource, including surveys, interviews, and observations with teachers and students using the ODI prototype. [19,108] demonstrate teachers' perspectives on open data in education and their assessment of open data's potential impact on students.

However, in the present study, teachers had the opportunity to interact directly with a range of pre-selected, school-related open data sets through the ODI. Thus, they could experience the ODI as developed based on the requirements they proposed in [153]. We investigated the research question in

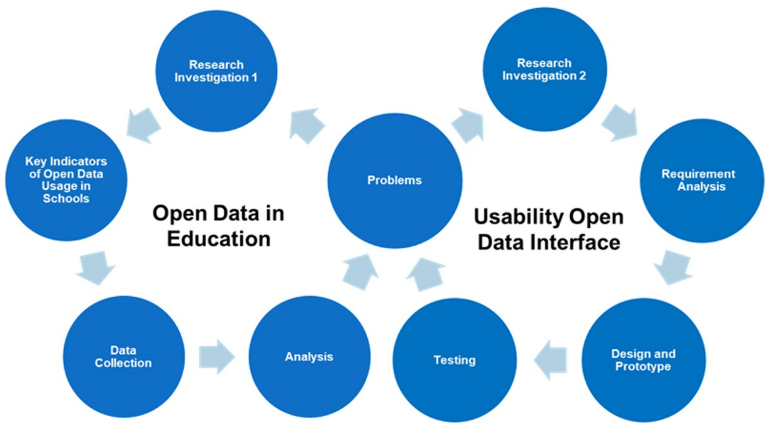

Fig. 7.1: Methodological approach inspired by the ethnographic approach [163], with Investigation 1 examining open data in education and Investigation 2 studying the usability of the Open Data Interface (ODI).

two parts, with two particular focus areas, using an ethnographic approach, as this has proved to be beneficial for understanding problems with existing designs and for generating new designs [163]. Applying this approach, we

[6]The ODI source code is available at `https://github.com/Open-Data-School/Open-Data-for-Schools.git`

investigated associated problems with open data practice in education using the ODI.

This approach allows users to work with open data directly through the ODI instead of a theoretically informed design only, but also helps identify any usability issues associated with ODI, as shown in Figure 7.1. Thus, in the first part, we investigated the associated opportunities with open data as an educational resource using the ODI. The second part focuses on the ODI's usability, e.g., whether the prototype fulfills the teachers' requirements.

3.1 Investigation 1: Open data as an educational resource

Investigation 1, focused on examining open data as an educational resource in an environment in which teachers have access to open data sets through the ODI. The teachers and students were the participants. Both qualitative and quantitative research techniques were used, such as one-on-one interviews, a focus group, online usability tools, a pilot test, questionnaires, online surveys, and open discussions to gather participant responses.

3.2 Investigation 2: Evaluation of our ODI prototype

In Investigation 2, the ODI's usability was evaluated. The methods applied in investigation 2 are:

1. **Usability test of the ODI prototype:** We tested the following aspects of the interface prototype, viewed as general aspects of any web interface [164, 165], as shown in Figure 7.2.

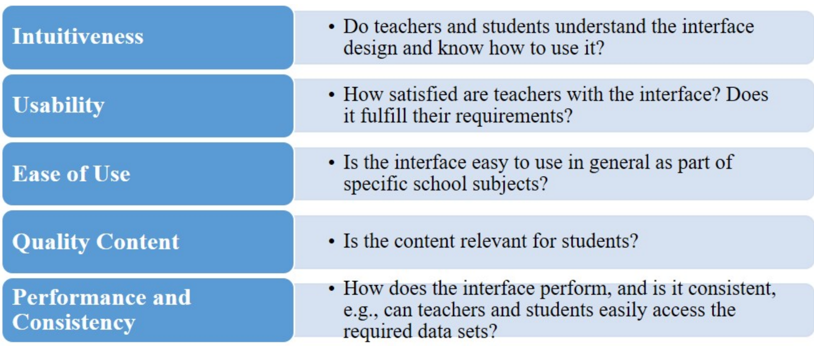

Fig. 7.2: General usability aspects used in testing the Open Data Interface (ODI). Inspired by [164] and [165].

During the testing of these aspects, the focus was on the platform's usability in relation to the educational domain. For instance, how it works as a learning tool in public schools, how it works in tackling educational challenges, and how well it fulfills the requirement models developed in [153].

2. **Modification of the ODI based on the usability test results:** The ODI modified iteratively after each round of data collection and analysis in Investigation 2. Initial data were collected through one-on-one interviews in which teachers tested the ODI's various features and provided feedback. Before setting up the focus group meeting with teachers, we upgraded the ODI to reflect the interview comments. Likewise, before launching the online usability test, we upgraded the ODI to its final version based on the focus group comments.

3.3 Test setups

Details are provided below on the different methods used to investigate both parts of the research question, i.e., assessing open data's potential and challenges as an educational resource and testing the ODI prototype's usability. The participant details are provided in Table 7.1.

1. **One-on-one interviews:** The main aim of using interviews was to get feedback from teachers after providing them with insights about open data and how they could use it as part of their teaching assignments using the ODI [166, 167]. Using this method, we tested the usefulness of the pre-selected open data sets, their visualizations, and the ODI interface's overall user-friendliness, and asked for any new features that might be interesting for teachers.

2. **Focus group:** Focus groups help gather in-depth details about a group's actions, thoughts, and feelings, as participants are allowed to interact and converse with others while discussing a topic [168]. In our case, the focus group was a mix of teachers of different subjects and grades (fifth through ninth). The main aim was to investigate the awareness of open data as an educational resource among teachers and subsequently to test the ODI's usability.

3. **Usability tests:** With usability tests problems can be identified before the system is released to end-users [169]. We used the Loop11[7] online usability test tool, which allowed us to analyze our prototype's usability while users were performing real tasks. We choose Loop11 because it allowed us to carry out usability tests remotely, i.e., without having to bring teachers into the lab. Loop11 provides two types of user testing: moderated and unmoderated. With moderated testing, users shared their screen and audio with the moderator (live) as they performed

[7] `https://www.loop11.com/`

Table 7.1: Data collection setup and participating teachers and students

Test setup	Participants	Schools	Grades	Subjects	Location	Duration
One-on-one interview	5	5	5th–9th	Math, Science	Aarhus, Horsens	1–1.5 hrs.
Focus group	25	12	5th–9th	Math, Science, Social science	Aarhus	1 hr.
Moderated online test	5	5	5th–9th	Math, Science, Social science, Geography	Aarhus, Aalborg, Horsens	45–60 mins.
Unmoderated online test	4	4	5th–9th	Math, Science, Social science	Aarhus, Aalborg, Horsens, Copenhagen	20–30 mins.
Pilot test with students	16	1	9th	Science	Aarhus	6 hrs.

their tasks. In unmoderated testing, users do their tasks at a time of their choice without a moderator, though screen and audio still can be captured. We did online testing with both types.

4. **A pilot test that included students:** One of the main aims of pilot tests is to increase research quality, reliability, and validity [170]. As students and teachers are the main users of the ODI, we also have run a pilot test in a public school in the city of Aarhus, where a teacher and students used the ODI in class as part of teaching assignments.

Teachers willing to participate in the research study were recruited based on their subjects, grade levels, and experience as follows:

1. Public schoolteachers with more than two years of experience
2. Grades: fifth through ninth (as in these grades, students start developing basic concepts on data and their presentation as part of mathematics and statistics.)
3. Subjects: mathematics, science, geography, and social sciences

Previous research and usability guides indicate that four or five participants can reveal approximately 80 percent of the usability problems in most web interfaces [171]. Similarly, using 10 participants usually will elicit detection of 90 percent of usability problems [172, 173]. Therefore, 4–10 participants were recruited for each test to evaluate the ODI's usability. Overall, 39 teachers and 16 students participated in the research study from fifth to ninth grades. All the interviews were conducted in Danish and recorded with the teachers' consent. Procedural details on each test setup are provided in Table 7.2.

Table 7.2: Procedural details for each test setup

Test setup	Procedure
One-on-one interviews	**Investigation 1:** The concept of open data was introduced to the participants. Questions were asked about open data potential, skills required to work with data, and any obstacles to using open data as part of teaching. Teachers had access to the ODI, so they could interact with different data sets in a real environment. **Investigation 2:** Teachers tested the ODI and tried out its various features, then provided feedback on the design of visualizations and suggested designs for learning activities using open data sets.
Focus group	**Investigation 1:** Teachers listened to a short (10-minute) presentation about open data and its possible use in public schools, followed by an open discussion on associated problems and opportunities in using open data in schools. Teachers discussed how often they use data in their teaching, from where they get the data, and in which subjects and grades they use data. They also discussed the impact of using data on students' learning skills, as well as obstacles of using open data in teaching assignments. Teachers also answered questions concerning the impact of open data on students in the form of a questionnaire.

	Investigation 2: Participants tested the ODI on their computers while suggestions and feedback were noted. The meeting ended with a post-test questionnaire to gauge participants' individual and subjective responses on the ODI's design and its usability in teaching activities.
Moderated online test	**Investigation 1:** For moderated testing, times and dates were set with users beforehand, with a brief explanation on how to participate in the online test. After solving different tasks to test the ODI prototype's usability, short, live interviews were conducted, in which we investigated the scope of open data in education and teachers' perspectives on open data and the ODI. **Investigation 2:** Tasks were designed to test ODI's usability. Six tasks and 10 questions were used. The tasks were designed to test teachers' understanding of the ODI using real data sets in their subjects. For example, teachers performed a task in which they identified pollution data sets from the City of Copenhagen as part of a science subject. The task details are given in Appendix 6.
Unmoderated online test	**Investigation 1:** A link to the test was sent to participants via email. The test included a short survey in which we asked both open-ended and closed-ended questions about the use of data in teaching, different ways of integrating open data in education, and educational open data sets to be included in the ODI. **Investigation 2:** The unmoderated test comprised five tasks and 13 questions. The questions were both open-ended and closed-ended, focusing on ODI's ease of use and general usability (see Appendix 6).
Pilot test with students	**Investigation 1:** The teacher started the day by briefly introducing the concept of open data and ODI to the students, using the concept of pollution with examples. The teacher also used the pollution data sets available in the ODI as real examples of their own cities' pollution levels at different locations. The conversations between teacher and students were recorded during the test.

Investigation 2: The teacher handed out an assignment that comprised different tasks on pollution that students had to complete in groups with the help of data from the ODI (see Appendix 10). At the end of the assignment, students also provided feedback on the ODI via an online questionnaire.

4 Results and discussion

In this section, we briefly discuss the results obtained from qualitative and quantitative data analysis. The results present our analysis on if and how open data can best play a central role in achieving learning goals, and how platforms like the ODI can help bridge open data and educational activities. The main themes arising from the results are summarized in Table 7.3 and discussed in more detail in the following sub-sections.

Table 7.3: Overview of results – major themes and sub-themes with example quotes from participants

Themes	**Sub-Themes**	**Example quotes**
Open data in education	1. Relating things to the real world 2. Educational open data sets 3. Learning activities using real data	*"Students will learn more when they relate things to their own real world, e.g., information about traffic, population, pollution, etc., and open data provide us a chance to learn through these real data sets." (Teacher 1, Jan. 12, 2020)*
Learning skills associated with open data	1. Critical Thinking 2. Teamwork 3. Discussion	*"Open data will help in developing students' learning skills like teamwork, critical thinking, discussion, and the ODI works very well, as everything is gathered at one place." (Teacher 1, June 26, 2020)*

Data skills	1. Meaning of data 2. Data analysis 3. Data visualization skills 4. Statistical skills	*"Open data are fantastic, but at the same time, it is also important that students are aware of the meaning of data, and for this, they must generate and analyze their own data because if students have not tried generating data themselves, then they do not understand data." (Teacher 1, Feb. 20, 2020)*
Challenges for open data in education	1. Unfamiliarity with using real data sets 2. Relevant educational data sets 3. Lack of data skills 4. Time constraints 5. Lack of resources	*"I want to use real data sets in my teaching, but it was really difficult to find relevant data sets from government websites, and it is hard to sort out the information we needed before we use them in our everyday teaching." (Teacher 1, Feb. 27, 2020)*
Open data web interface	1. Identifying relevant and useful open data sets 2. Integrating educational open data sets 3. Intuitive/readily learned design 4. Usability 5. Ease of use 6. Quality content 7. Performance	*"Instead of searching and sorting data sets, and consuming too much time, I like the idea of a simple and easy-to-use ODI for schools. We can easily integrate real data sets into our teaching using this interface." (Teacher 2, Feb. 27, 2020)*

Challenges tied to ODI's integration in schools	1. Administrative constraints 2. Up-to-date 3. Training 4. Ministry of Education approval	*"ODI is great; it provides the information that will make our teaching activities more interesting, but for using it as part of our subjects, it is also important that it must be up-to-date, and it will be great if the Ministry of Education also approved it." (Teacher 2, June 26, 2020)*

4.1 Open data in education

The results under this theme demonstrated that there are perceived opportunities associated with the use of open data in public schools. Some teachers already included real data sets in their teaching activities, but teachers also faced challenges in using open data in their teaching plans, e.g., they often were unaware of the open data portal for their city or how they could include open data sets as an educational resource in their teaching.

Relating things to the real world

Using the ODI, teachers developed a clear impression of the range of different educational data sets that they could include in teaching. They also provided their perspectives on how open data could help students develop data skills and what could be the impact of open data on education through the study's interviews, surveys, and a focus group meeting.

For example, using real facts about their cities could capture students' attention and lead to more students participating in discussions. Teachers also believe that using open data in education can help advance both digital and data skills. Teachers mentioned that students achieve a better understanding of a topic if they have relevant data in front of them. Furthermore, open data provide an opportunity for students to understand and interpret the data they observe in their surroundings.

Educational open data sets

Teachers suggested additional open data sets that could be interesting for students to include in the interface, such as water quality, forests, crimes, pollution sources, traffic, plastic pollution, lakes (locations, length, etc.), etc.

Learning activities using real data

One of the main obstacles among teachers is the lack of awareness in integrating open data in teaching. During Investigation 1, we also gathered suggestions from teachers about how to integrate real data sets into their assignments. For example, teachers suggested different ways to analyze the city's population in the past five years and predict future population aspects based on the data as part of social science. Similarly, geographical data sets could be used to help students understand their own cities' geographical structure from a variety of perspectives.

4.2 Learning skills associated with open data

During the focus group meeting, teachers discussed various learning skills that can be associated with open data depending on how data is used in an instructional design. At the end of the focus group meeting, in a post-test questionnaire, we asked teachers to select 21st-century skills according to students' grades that can be associated with open data among the skills listed by [16, 174] as important issues.

Critical thinking, teamwork, and discussion are considered as important 21st-century learning skills according to teachers for students and can be improved and developed with the use of open data in teaching assignments. The details are discussed below.

Critical thinking

Critical thinking allows students to ask questions and make value judgments [175]. At the end of the focus group, teachers provide their responses in a post-test questionnaire about various associated skills with open data, and critical thinking is one of them. Altogether, 23 of 25 teachers believe that students in fifth to ninth grades can develop this skill using real data, e.g., how to reduce pollution levels near their schools, how to reduce energy consumption, or how energy waste could affect the environment and the planet overall.

During the pilot test, students were observed while making discussions with their teacher. Students asked questions about pollution levels in their cities during different times of the day and how to reduce them, considering critical aspects of pollution's effects on society.

Teamwork

Learning assignments based on educational open data sets provide an opportunity for students to work in teams, which is also an important skill for students' learning development. Altogether, 23 out of 25 teachers responded in a post-test questionnaire (during the focus group meeting) that through the use of real data, students in fifth through ninth grades can work in groups to solve problems by interpreting and understanding the data. During the pilot test, students worked in groups and discussed how they could reduce pollution in their cities. It also demonstrates how real information about students' cities makes the subject interesting, and group work can become more interactive when students have real information about their surroundings.

Discussion

Using real information, students will have more opportunities to discuss a topic. Using open data, students have access to real information on their cities and surroundings that will make the class environment more interactive and open the door to discussions. All 25 teachers who participated in the focus group agreed that real information always captures students' attention and that students in fifth through ninth grades can participate actively in discussions in class more easily when they are based on real data.

4.3 Data skills

Working with different types of data allowed students to build and improve data and digital skills, e.g., computer skills, visualization skills, data-handling skills, etc. However, students also encountered issues when working with open data, such as the data concept being too abstract, and they required additional assistance to understand how data is used to understand a problem. Furthermore, students also lose interest due to some out-of-date data sets. In some cases, teachers suggested that it is important for students to collect and interpret data themselves. This will help in understanding the concept of data and how to solve problems using data. The results are discussed below.

Meaning of data

The concept of data itself is difficult for students to understand, as they are unfamiliar with how data are collected, why data are important, and how data are used to find solutions to problems. Teachers have suggested including data collection activities in the classroom, so students can get familiar with data and their use in everyday life. One of the participants said:

"To explain the concept of data to students, they must work with different types of data collected by them. Students need prior knowledge before they can use and understand the data." (Teacher 3, Feb. 27, 2020)

Data analysis

Introducing the concept of data collection in the classroom can give students the necessary background to sample, analyze, and discuss their data. Working with real data sets enables students to organize them into tables and different folders according to information types. Out of 25 teachers, the 24 who participated in the focus group meeting suggested that students in fifth through ninth grades can develop basic data-handling skills if they work with small data sets more often in their assignments. For example, students can use pollution data sets to get the information they need in the form of a small table to complete an assignment, instead of using all the details provided in pollution data sets.

Data visualization skills

Using open data, different information can be presented in the form of simple graphs and visualizations. This not only allows students to understand how data are used to present information but also can enable them to examine graphs and visualizations to answer related questions and understand how to use different forms of graphs and visualizations while improving their computer skills.

Statistical skills

Using open data in the classroom can improve students' statistical skills, according to teachers' feedback. Students can perform basic mathematical operations, such as converting information from annual to month by division methods or calculating means, etc. Altogether, 24 out of 25 teachers participating in the focus group meeting agreed that students in fifth through ninth grades easily can improve and develop such skills.

4.4 Challenges for open data in education

Teachers also pointed out potential challenges and suggestions on using open data in schools during the interviews and focus group meeting. Overall, the teachers were satisfied with the ODI's design, which allowed them to access educational data sets from their cities as part of different school subjects, but they also mentioned didactic challenges (see subsection under 4.5 *Integrating educational open data sets*) and the following technical challenges:

Unfamiliarity with using real data sets

One of the main challenges is unfamiliarity with open data as an educational resource. Teachers are not aware of the concept of open data and how they could integrate it into their teaching, but this lack of awareness could be alleviated through workshops, training, and seminars.

Relevant educational data sets

Teachers are unaware of open data portals, and they mostly use national statistical websites, in which they need permission in some cases, and also need to clean the data. Arranging workshops and seminars with success stories in which teachers share their own experiences accessing relevant data sets as part of their teaching could solve this problem.

Lack of data skills

Teachers need data skills to extract smaller data sets from bigger ones. They also might need computer skills to present or explain different graphs to students. Training and short courses can extend teachers' existing skills to work with open data.

Time constraints

Teachers also need extra time to collect real data sets from their surroundings as part of their subjects. It will take both time and effort to identify relevant data sets using open data portals, and teachers need a platform from which they can get relevant data sets as part of their subjects. If the ODI could be linked with textbooks, teachers would get advice on when to use which data sets and visualizations to explain a certain topic and guide them on how to use educational open data sets without spending too much extra time and effort.

Lack of resources

One of the challenges that teachers discussed in integrating open data into schools is limited resources in public schools, such as computer labs not always being available, or students not having their computers. However, these problems could be solved by managing the timetable. Some teachers pointed out to integrate the ODI into their teaching plans, it is also important for the Ministry of Education to approve it, and that such platforms must contain up-to-date information.

4.5 Open data web interface

Under this theme, we focus on the ODI's usability. We tested different aspects of the prototype during Investigation 2 and upgraded the prototype before the final online usability test.

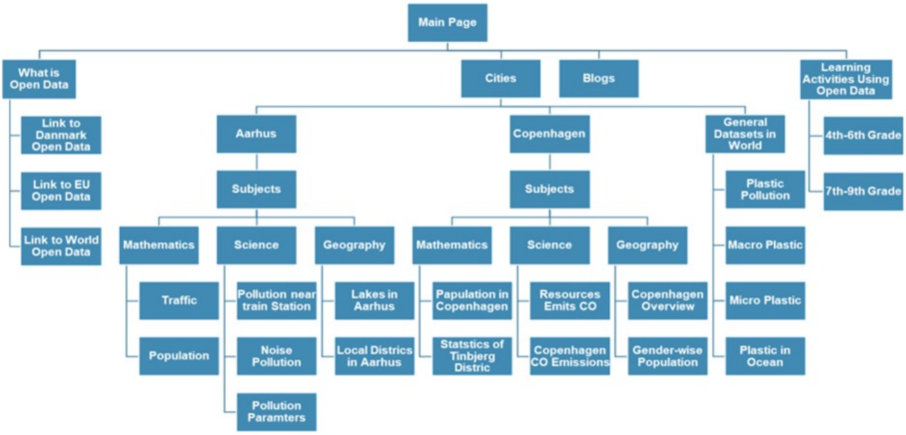

Fig. 7.3: Sitemap of the the final Open Data Interface (ODI) prototype

The ODI design was based on requirements identified by teachers using Enterprise Architecture Oriented Requirement Engineering approach [153]. The main page provides general information on open data and its use in education and allows for navigating to open data of several cities categorized by subjects. Figure 7.3 shows a sitemap of the final ODI platform, and Figure 7.4 (on the next page) shows part of the front page and examples of data visualizations from the ODI. The platform is available at `https://odw.aau.dk/` and is open source[8], apart from the visualization tool Tableau used to create graphs. Brief results on the ODI's usability aspects are discussed below.

Identifying relevant and useful open data sets

Real data collection can be time-consuming and otherwise impractical without data skills in schools. With the availability of open data, teachers can carry out learning activities using real data without needing to leave the classroom. However, teachers still need help with searching and filtering relevant educational open data sets from open data portals. According to the results from one-on-one interviews and focus group meeting, teachers believe that they can find educational data sets by subject category through ODI without spending extra time searching and filtering relevant information from different portals. Furthermore, they would use the ODI more often if more and different data sets and graphs were included. One teacher said:

[8]The ODI source code is available at `https://github.com/Open-Data-School/Open-Data-for-Schools.git`

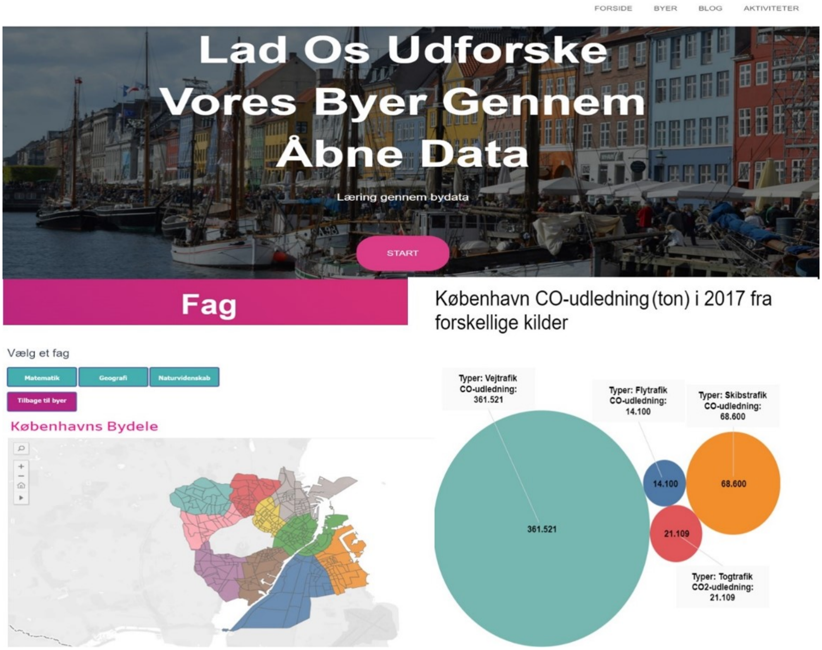

Fig. 7.4: Front page and example of data visualization available in the ODI prototype

"I think I would use the ODI often depending on what it contains; if there will be more data sets and graphs, then definitely I would use it very often." (Teacher 4, Feb. 27, 2020)

Integrating educational open data sets

Teachers view ODI as helpful in integrating real educational data sets in the classroom environment. ODI provides access to open, direct, relevant, educational data sets as part of math, science, and geography subjects. Teachers also recognize the benefits of integrating open educational data sets in the classroom, as they facilitate students' active involvement in the learning process and teaching assignments.

Intuitive/readily learned design

Under this theme, we focused on identifying whether teachers easily can understand the interface design and use it in the classroom environment. During the initial one-on-one interviews and the focus group meeting, the teachers suggested that the main page requires a simple description and that the text should be simple for students. They also suggested that figures, tables, and examples be included, instead of just text, to make it more interesting for students. Teachers also suggested including a comments section for each visualization to provide feedback. Before the online usability test, we upgraded the main page and visualization sections according to the teachers' feedback.

Usability

To test the ODI's usability, we used both qualitative and quantitative data collection methods during the one-on-one interviews, focus group, and online usability testing with Loop11, through which teachers completed various tasks in the ODI. The results from the interviews and focus group meeting demonstrate that the perceived usability of the interface depends on the subjects and class grade. Teachers judge that students in fifth through sixth grades can use the ODI to utilize relevant graphs, and students in sixth through ninth grades can use the ODI to complete assignments based on these graphs. Moreover, the ODI was viewed as most useful for science subjects and maths, as science and math teachers found the ODI to be more relevant to their teaching. However, some teachers required extra knowledge about how to use these real data sets. The focus group post-test questionnaire results indicated (see Figure 7.5) that teachers found it easy to use the ODI and found the visualizations relevant and simple (e.g., bars, pie charts, etc.) for use in schools as part of teaching activities. Before the online usability

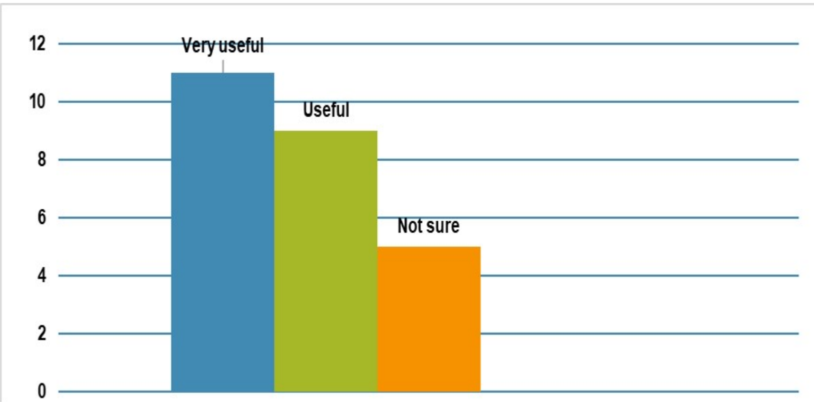

Fig. 7.5: Perceived usefulness of the Open Data Interface (ODI) from the focus group post-test questionnaire (N=25)

test with Loop11, the ODI was updated to its final version according to the requirements identified during the focus group, such as more detailed descriptions of visualizations, and a comment section added at the end of each visualization to get teachers and students' feedback.

The moderated Loop11 test results demonstrated that the ODI has the potential to help teachers use open data more often in their teaching practice, such as when explaining different topics using real information from students' surroundings (e.g., details on population or pollution levels), as well as to allow students to collect their local data and compare them with the city's open data. The average time duration needed to complete such tasks is provided in Table 7.4. The average time varies between 0:57 and 1:57 minutes, and the standard deviation varies from 23 to 53 seconds for performing a task. Teachers performed 90% of the tasks successfully. They also answered open-ended closed-ended survey questions regarding open data and the ODI. Teachers also provided their response to the standard system usability questionnaire (see Appendix 8).

Table 7.4: Average duration, standard deviation (S.D.), and avg. page views per task in the moderated usability test (N=5).

Task	Description	Success	Duration (min)	S.D. (sec)	Page views
1	Main page	80%	1:57	42.11	3
2	Open data in geography	80%	1:52	52.50	3
3	Finding relevant blog	100%	1:01	22.71	3
4	Open data in mathematics	80%	1:32	26.01	5
5	Open data activities	100%	0:57	30.02	4
6	Comments	100%	1:05	26.11	5

Teachers who were not frequent users of computers took longer to complete the tasks, e.g., three out of nine teachers who took longer than the rest of the participants did not use computers in their everyday routines. Also, the math and science teachers understood the tasks quickly and completed them with a few clicks. For example, geography and social science teachers took a little longer (average, 01:15 minutes) and longer paths (average page views: four) to complete the tasks than math and science teachers (average, 00:50 minutes, with two page views on average).

During the unmoderated test, the average time and standard deviation for the unmoderated test vary between 0:39 to 1:03 minutes with a standard deviation of 17 to 41 seconds for performing a task. The users performed 100% of the tasks successfully and provide their response to the standard system usability questionnaire (see Appendix 9). Table 7.5 provides the results on average time duration, standard deviation, and page views per task in the unmoderated test.

During the pilot test, students also provide feedback on the usability of ODI in an online questionnaire. In general, 2 out of 16 students thought that

Table 7.5: Average duration, standard deviation (S.D.), and avg. page views per task in the unmoderated usability test (N=4).

Task	Description	Success	Duration (min)	S.D. (sec)	Page views
1	Main page	100%	0:51	40.46	3
2	Open data in geography	100%	1:03	38.79	7
3	Finding relevant blog	100%	0:39	24.25	4
4	Open data activities	100%	0:46	17.22	4
5	Comments	100%	0:50	25.54	6

some graphs were difficult to use, such as finding lake locations, and that more descriptions should be added. However, 15 students found it simple to switch between graphs. They also provide feedback on the overall design of the ODI, such as suggesting the use of facts box with general information as well as the use of larger text fonts in bright colors, and the use of symbols in descriptions text.

Ease of use

As the main users of the interface are students and teachers, it is important that they can use the ODI easily and understand the information provided. During the interviews and focus group meeting, participants tried different features of the ODI and found it easy to use overall. However, they pointed out minor navigation problems, e.g., a missing back button, which was resolved before the online usability test.

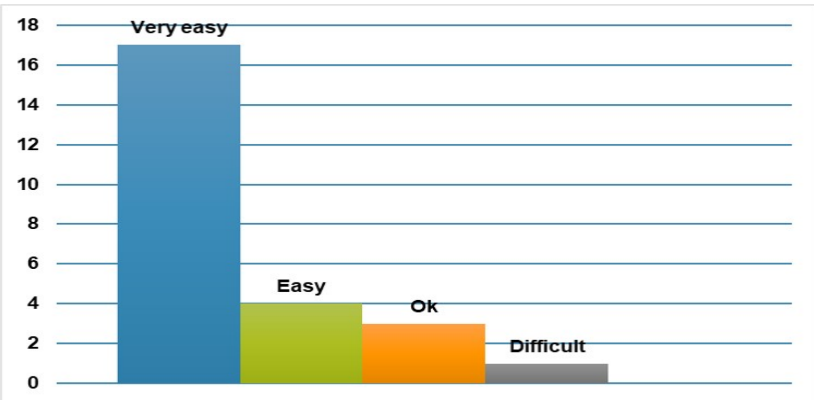

Fig. 7.6: Perceived ease of use of the Open Data Interface (ODI) – from the focus group post-test questionnaire (N=25)

Figures 7.6 and 7.7 provide teachers' responses collected during the focus group concerning ease of use with the ODI and visualization. During the pilot test, students were observed and recorded while they completed assignments on pollution using the ODI. Generally, they used ODI without problems. Altogether, 14 out of 16 pupils said that ODI is easy to use, and 15 out of 16 found it easy to complete assigned tasks using ODI. Among nine teacher participants, eight in the online usability test rated ODI as easy to use, simple, and well-integrated.

Fig. 7.7: Perceived difficulty of the visualizations used in the Open Data Interface (ODI) – from the focus group post-test questionnaire (N=25))

Quality content

During the one-on-one interviews, the teachers suggested that data sets should be categorized under subjects for each city, and they suggested that data sets – such as plastic pollution, environmental pollution, forest, etc., be included for each city so that students can compare the information with other cities easily. We upgraded the ODI, i.e., categorized educational data sets under subjects for respective cities and included pollution and environmental data sets in the final version before launching the moderated and unmoderated tests with teachers and the pilot test with students. Figure 7.8 provides teachers' responses collected through the focus group concerning ODI content quality. During the pilot test, 14 out of 16 students found the graphs and visualization easy to understand, but two students had some difficulties in understanding the graphs.

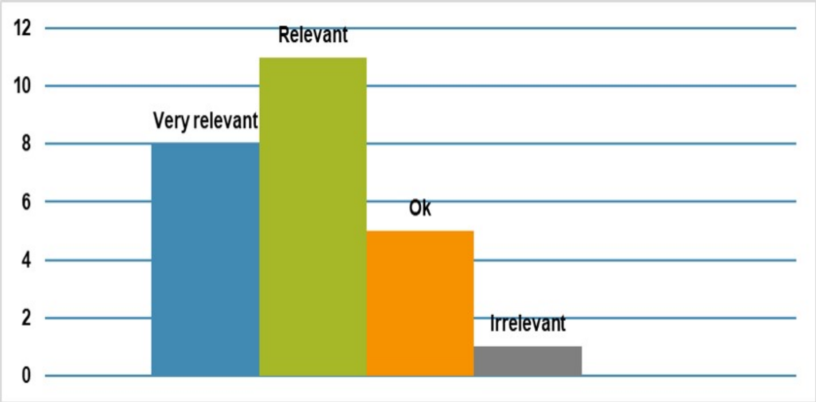

Fig. 7.8: Perceived quality of the Open Data Interface (ODI) content – from the focus group post-test questionnaire (N=25)

Performance

The performance aspect includes response time, wait time, load time, CPU utilization, and memory utilization. The ODI's overall performance was viewed as satisfactory according to feedback from teachers, but in some cases, the visualization software took a while to load. Figure 7.9 provides teachers' assessments of the ODI's overall performance during the moderated and unmoderated testing.

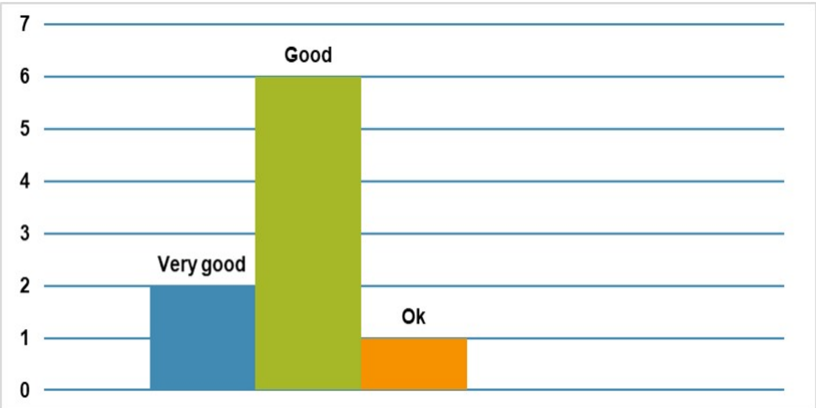

Fig. 7.9: Perceived level of performance by the Open Data Interface (ODI) – from moderated and unmoderated usability tests (N=9)

4.6 Challenges tied to ODI's integration in schools

During Investigation 2, we identified challenges or barriers that could influence use of the ODI .

Administrative constraints

According to feedback from teachers, there may be administrative constraint hurdles to integrate the ODI, such as permissions to install visualization software or computer labs' availability.

Up to date

It is also important that ODI contain up-to-date information. Some data sets contain information from the previous year, but others that contain data on topics such as temperature shifts and pollution should be up-to-date so that students can make comparisons with their own data sets, e.g., temperatures during different parts of the day. As one participant said:

"The ODI is interesting because you can get data at one place; it will be more useful if it will be up to date periodically. For example, if I want to compare our school temperature data collected through Data-logger, then with the updated information on ODI, it will be possible to compare own temperature data with the center of Aarhus." (Teacher 5, Feb. 27, 2020)

Training

The results also demonstrate that teachers who are not frequent computer users find it difficult to use data portals or the ODI. They need training and workshops to learn how they can use data to facilitate their subjects.

Ministry of Education approval

Teachers also have suggested approving the ODI from the Ministry of Education. It will make teachers more confident in using ODI as part of their teaching activities and overcoming any administrative barriers. As one teacher said:

"We spend a lot of time with the students to teach them that they can't just choose any website. If the ODI is approved by the Ministry of Education, then it becomes easier to justify why to choose this instead of others." (Teacher 6, Feb. 27, 2020)

5 Conclusion

In this article, we have investigated and tested the ODI's usability in terms of real educational data sets in public school teaching. The ODI can bridge the gap between open data opportunities in the educational sector and its frequent use in educational activities. With the development of the ODI, we can open data exploration practices to the younger generation of learners as part of their subjects.

In four different setups, we investigated our research question, i.e., examining the opportunities and skills associated with open data in education and the ODI's usability in public schools. Teachers also provided views on data skills that can be enhanced with the use of open data in education. Based on teacher and students feedback we upgraded the ODI to the final version by removing minor problems and adding more features. For example, detailed and simple guidelines for each visualization have been added so that teachers and students can understand and interact with visualizations, and comment boxes were added at the end of each visualization so teachers can provide feedback on different graphs and visualizations.

In the future, we will study data collection methods using sensors and applications in schools that could provide students with a solid understanding of the concept of data and its use in their surroundings and the use of sensor data in combination with open data.

6 Appendix: Tasks used in the usability test

All the tasks used in the online usability test were in Danish language and their description are given below. These tasks are used both in moderated and unmoderated usability test setting.

Opgaver 1: Forside

Se om forsiden giver nogle grundlæggende informationer omkring åbne data samt links til danske, europæiske og internationale åbne data portaler. Når du gennemført opgaverne bedes du højt og tydeligt verbalisere dine tænker og handlinger.

Opgaver 2: Åbne data i geografi

Du underviser et emne omkring strømme og søer i geografi i 6. klasse. Du vil gerne vise forskellige vandløber og deres længde i Århus til dine elever. Se om du kan find relevant information på hjemmesiden.

Opgaver 3: Find relevant blog

Du har hørt, at Aalborg Universitet har publiceret en interessant artikel "Hvorfor åbne data", omkring brugen af åbne data i skoler, og du vil gerne læse denne. Se om du kan finde teksten på hjemmesiden.

Opgaver 4: Åbn data i matematik

Gå ud fra at du underviser matematik til en 7. klasse, og du vil gerne inkludere et eksempel på befolkningen i Københavns distrikter (befolkning i København).
Hvordan vil du forsætte?

Opgaver 5: Åbn data aktiviteter

Du har hørt om den succesfuld brug af åbne data i skolerne som del af forskellige undervisningsaktiviteter, og du vil gerne bruge disse virkelige datasæt i dine egne undervisningsopgaver. Men du ved ikke, hvordan du skal starter, og du har brug for nogle eksempler på designe af aktiviteter til 6. klasseelever til brugen af åbne data.
Hvordan vil du fortsætter?

Opgaver 6: Kommentarer

I den klasse, som du underviser i naturvidenskab, diskuterer I forskellige kilder, som er ansvarlige for forurening. Du vil gerne vise, hvor meget CO som udledes i København fra forskellige kilder. Da du åbner grafen, opdager du, at der mangler information, og du vil gerne skrive en kommentar for at forbedre grafen.
Hvordan vil du gøre dette?

7 Appendix: System usability survey

Participants also provided their responses to system usability questionnaire. They provide their feedback about the general features of the ODI. The survey is in Danish and below are the questions used in the survey.

Angiv hvor enig eller uenig du er i følgende udsagn på skalaen:

1.	Jeg tror, at jeg ville have lyst til bruge dette system ofte.
2.	Jeg fandt systemet unødvendigt komplekst.
3.	Jeg synes, at dette systemet var let at bruge.
4.	Jeg tror, at jeg ville få brug for support for at kunne bruge dette system.
5.	Jeg fandt ud af, at de forskellige funktioner i dette system var godt integreret.
6.	Jeg synes, at der var for meget inkonsistens i dette system.
7.	Jeg kan forestille mig, at de fleste mennesker ville lære at bruge dette system meget hurtigt.
8.	Jeg fandt systemet meget besværligt at bruge.
9.	Jeg følte mig meget sikker i at bruge systemet.
10.	Jeg havde brug for at lære en masse ting, før jeg kunne komme i gang med dette system.

8 Appendix: Responses to system usability questionnaire during moderated online usability test

All 9 participants filled out the system usability questionnaire during the online usability tests using loop11. 5 participants participated in moderated usability test. Below is the overview of the responses with details.

	Meget uenig	Uenig	Hverken enig eller uenig	Enig	Meget enig
Jeg tror, at jeg ville have lyst til bruge dette system ofte	0 0.0%	2 40.0%	2 40.0%	1 20.0%	0 0.0%
Jeg fandt systemet unødvendigt komplekst	1 20.0%	2 40.0%	2 40.0%	0 0.0%	0 0.0%
Jeg synes, at dette systemet var let at bruge	0 0.0%	0 0.0%	1 20.0%	3 60.0%	1 20.0%
Jeg tror, at jeg ville få brug for support for at kunne bruge dette system	2 40.0%	0 0.0%	2 40.0%	1 20.0%	0 0.0%
Jeg fandt ud af, at de forskellige funktioner i dette system var godt integreret	0 0.0%	0 0.0%	2 40.0%	2 40.0%	1 20.0%
Jeg synes, at der var for meget inkonsistens i dette system	0 0.0%	3 60.0%	2 40.0%	0 0.0%	0 0.0%
Jeg kan forestille mig, at de fleste mennesker ville lære at bruge dette system meget hurtigt	0 0.0%	1 20.0%	2 40.0%	1 20.0%	1 20.0%
Jeg fandt system meget besværligt at bruge	2 40.0%	2 40.0%	1 20.0%	0 0.0%	0 0.0%
Jeg følte mig meget sikker i at bruge systemet	0 0.0%	0 0.0%	1 20.0%	2 40.0%	2 40.0%
Jeg havde brug for at lære en masse ting før jeg kunne komme i gang med dette system	1 20.0%	2 40.0%	1 20.0%	1 20.0%	0 0.0%

9 Appendix: Responses to system usability questionnaire during unmoderated online usability test

Four participants participated in unmoderated usability test and filled the system usability scale. Below is the overview of the responses with details.

	Meget uenig	Uenig	Hverken enig eller uenig	Enig	Meget enig
Jeg tror, at jeg ville have lyst til bruge dette system ofte	0 0.0%	0 0.0%	2 50.0%	2 50.0%	0 0.0%
Jeg fandt systemet unødvendigt komplekst	0 0.0%	3 75.0%	0 0.0%	1 25.0%	0 0.0%
Jeg synes, at dette systemet var let at bruge	0 0.0%	0 0.0%	0 0.0%	4 100.0%	0 0.0%
Jeg tror, at jeg ville få brug for support for at kunne bruge dette system	0 0.0%	3 75.0%	0 0.0%	1 25.0%	0 0.0%
Jeg fandt ud af, at de forskellige funktioner i dette system var godt integreret	0 0.0%	0 0.0%	0 0.0%	4 100.0%	0 0.0%
Jeg synes, at der var for meget inkonsistens i dette system	0 0.0%	2 50.0%	0 0.0%	2 50.0%	0 0.0%
Jeg kan forestille mig, at de fleste mennesker ville lære at bruge dette system meget hurtigt	0 0.0%	0 0.0%	0 0.0%	4 100.0%	0 0.0%
Jeg fandt systemet meget besværligt at bruge	0 0.0%	3 75.0%	0 0.0%	1 25.0%	0 0.0%
Jeg følte mig meget sikker i at bruge systemet	0 0.0%	0 0.0%	1 25.0%	3 75.0%	0 0.0%
Jeg havde brug for at lære en masse ting, før jeg kunne komme i gang med dette system	0 0.0%	3 75.0%	0 0.0%	1 25.0%	0 0.0%

10 Appendix: Tasks used in the pilot test with students to test the usability of ODI

Opgaver 1

CO2-udledning i København – hvilke data kan du finde?

Opgaver 2

Hvilke CO-kilder er de værste i København? Hvad kan man bruge tallene til?

Opgaver 3

Sammenlign luftforureningen i Århus. Hvad kan man udlede af data?

Opgaver 4

Måling af CO, NO2, TEMP og Lyd i Århus - Hvad kan man bruge disse data til?’

Opgaver 5

Hvor mange vandløb løber til/fra Egå Engsø? Hvor mange af disse er naturlige?

Opgaver 6

Find alders og kønsmæssig fordeling af befolkningen i København. Hvad viser denne og hvad kan vi bruge den til?

Chapter 8

Paper 5: Towards using sensors as data sources in teaching: Requirements for school curricula-compatible sensors

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Abstract

The continuous innovation in modern technologies in various sectors of society has transformed everyday life. It becomes imperative for the educational community to equip the future generation with digital skills. In this article, using qualitative and quantitative research techniques, we define criteria for school curricula-compatible sensors (particularly, for secondary school students in grades 5 through 9). We also develop requirements models for sensor classes that satisfy the school curricula compatibility criteria using requirements engineering techniques. The results show that integrating sensors into schools can improve students' digital and data skills. Additionally, requirements models can help in developing school curricula-compatible sensors or transforming existing sensors into curricula-compatible sensors.

Keywords

School education; sensors; digital skills; data skills requirements for physical systems; technology requirements.

1 Introduction

The importance of sensor technology is growing continuously. Using sensor technology, we can explore and monitor our surroundings in ways that were not possible even a few years ago. New sensor technology variations and applications are advancing rapidly and expanding their scope and impact on everyday life. Sensors that are simple to use and handle can be used in a variety of domains, including education, rather than just technical domains. Among the advantages of sensor technology's use in education is that it provides students with a means of observing, interpreting, and investigating different phenomena in real-time [176]. The hands-on methods involved in using sensor technology to collect and analyze data also seem useful for students who find math and science lessons difficult [177]. Data-collection activities and experiments encourage critical thinking, allowing students to engage in real investigations rather than prescriptive experiments that have pre-determined outcomes. Bringing sensors into schools will not only help students in addressing the real problems of their neighborhoods and surroundings but also attract students' attention and motivate involvement in school lessons. Using sensors in the teaching can motivate students to follow science subjects. Their use also provides students with a means to determine how they can collect data about the real world surrounding them and how they can make decisions based on the collected data, e.g., about the classroom environment, traffic flows outside their schools, pollution levels, etc.

An alternative to sensor data is open data, which is becoming increasingly available. In school subjects, open data can also provide real information about students' surroundings and cities using simple visualizations and graphs [19]. However, the open data concept itself can be obscure to students, and they need hands-on experience of why and how data is generated and how the data can be analyzed and interpreted. With data-collection activities using sensors, students can collect data and analyze it as part of their lessons. Students can also collect sensor data on relevant topics, e.g., pollution levels around the school area, and compare it with available open data, for instance, data provided via the Open Data Interface[1] designed for Danish public schools [61].

The integration of sensor technology into the curricula is not only propitious to several ways of instruction and learning but can also be beneficial in understanding and investigating the immediate surroundings of the students [178]. A fundamental obstacle in learning data science, especially at the school level, is that children do not understand how science is relevant to them [179]. Sensor technology can play an important role to help children understand more about their physical and material environment. However, for the successful use of sensors in schools as part of everyday teaching, we need to define criteria for the design of curricula-compatible sensors. We will investigate the following research question:

"How can sensors facilitate the understanding of data and working with real-world data, and how can sensors be designed for use in education?"

This article makes the following main research contributions:

1. It identifies several possibilities in which the use of sensors can help students learn digital and data skills.
2. It identifies main classes of school curricula-compatible sensors.
3. It proposes requirements models that help to identify attributes relevant for school curricula-compatible sensors.

Our study is part of the Community Drive project[2], which is aimed at secondary school students aged 11–15 years, with a particular focus on data and technology integration into schools. We will thus use the term students for secondary school students aged 11–15 in the rest of the article.

The article is organized as follows. In Section 2, the background of sensors' use in schools is discussed. Section 3 presents the research design for defining the criteria and developing requirements for curricula-compatible sensor classes. Section 4 presents the results of our one-on-one interviews, focus group study, and pilot tests with key stakeholders, i.e., teachers and students. Finally, Section 5 presents a short discussion and the conclusions.

[1] https://odw.aau.dk/

[2] https://www.communitydrive.aau.dk/

2 Background

In this digital era, the younger generation of school students needs real-world skills to address the needs they will face in the future, such as critical thinking, collaboration, discussion, creativity, teamwork, imagination, and problem-solving [16]. Sensor technology can change the traditional ways of teaching science in schools by changing the learning environment and advancing the teaching methods of science and mathematics [180]. A sensor is generally defined as "a device that detects or measures a physical property and records, indicates or responds to it" [181] Sensors are designed to generate data, and the data is used to examine and find solutions to problems in our surroundings. Using sensor technology, students can become more creative and develop their social, linguistic, cognitive, visual, and emotional skills [182–184].

Researchers have discussed various studies of integrating sensors and their advantages in educational activities within secondary and primary schools. For instance, [185] reports positive experiences of using sensors in primary schools with students aged 7–8 years in the UK. The authors used probes and data-logging software to introduce dynamic line graphs to young children from the science investigations perspective. Additionally, [44] discusses a case study in which first-grade students collected weather data during the school year and designed several graphs to represent their data. The results show a high level of interest in data-collection experiments and describe how first-grade students worked with the graphs and maps. Other positive experiences have been reported in well-controlled studies by [186] in Cyprus and by [56] in the USA. The results show how children can handle data logging equipment and learn with it. From another perspective, many researchers, e.g., [45, 46] have shown that students lose interest and self-confidence in mathematics and other science subjects. However, by using sensors and technology, these subjects could become interesting in primary and K-12 school systems. A paper by Grufberg and Jonsson, 2012, [187] discusses a way to motivate children to learn about science by creating a design process scenario. The resulting design concepts demonstrated several innovative uses of sensor technology, indicating students' understanding of the technology and the natural phenomena under consideration. The sensor-oriented activities also encouraged discussions and reflections around the abstract concepts. A formal study [188] conducted in Cape Town, South Africa used a commercially available technology toy, littleBits. The authors explored the potential of littleBits as a learning tool for computational thinking in three different educational settings. The findings show that, in addition to engaging students in the play, littleBits provided opportunities for students to discover computational technology insights, practices, and perspectives. Also, the projects under the Micro: bit Educational Foundation [49] aim to bridge the gap between abstract data concepts and tangible experiences at the elementary and secondary school levels using a small programmable and embeddable computer-designed device.

Although sensor integration in education is beneficial, there is a lack of research in identifying the requirements for sensors that can be easily integrated into teaching. For sensor integration into school curricula, it becomes vital to analyze teachers' and students' needs and to define criteria for curricula-compatible sensors that could appropriately facilitate educational activities, for instance, being easy to handle, safe, simple in data presentations, etc. For this, we also have to classify sensors into relevant curricula-compatible classes that could be integrated with school subjects and we have to identify the requirements for such sensor classes under different conditions, i.e., indoor and outdoor. Moreover, analysis of existing sensors is also needed to determine whether they are school curricula-compatible or not and which adjustments are required to achieve the compatibility.

3 Research design and methods

The research study was carried out in two steps, R1 and R2, to investigate the stated research question (see Figure 8.1). In the first step, we identified the

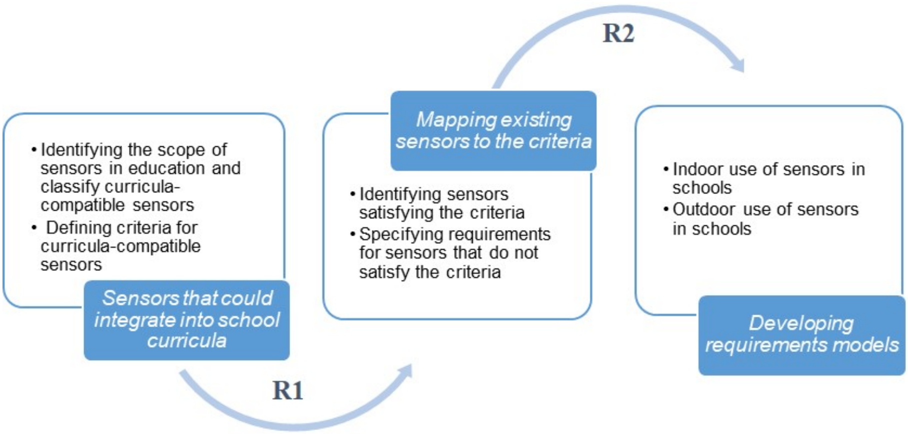

Fig. 8.1: Research design to answer the research question "How can sensors facilitate the understanding of data and working with real world data, and how sensors can be designed for use in education?

role that sensors might play in education, e.g., how sensor technology can be used for developing digital and data skills. We first identified the relevant curricula-compatible sensor classes that could be integrated into teaching as part of school subjects through interviews and a focus group meeting with teachers as participants. Then, the criteria for the attributes of the identified curricula-compatible sensors classes were defined based on teachers' feedback. In general, certain attributes must be considered when we choose a sensor, e.g., accuracy, environmental conditions, calibration, cost, and repeatability, as discussed in [181]. The second step R2, determines whether the existing sensors already used in educational activities satisfy the criteria for curricula-compatible sensors, and if not, what adjustments are needed to achieve this compatibility. Finally, requirements models for curricula-compatible sensors are developed under specific conditions, i.e., indoor and outdoor.

R1: Criteria and classes for curricula-compatible sensors

For revealing ways of integrating sensor technology into schools, we used one-on-one interviews and a focus group meeting methods. We approached 30 schoolteachers of grades 5–9 (students aged 11–15 years) and recorded their perspectives on the use of sensors in schools. We investigated how often they used sensors in their teaching, what made a sensor compatible for educational activities, and what were the requirements for such sensors. We also investigated why sensor use is essential in the educational domain and how students can take benefit from sensors as part of everyday learning activities. The focus group meeting and all the interviews were conducted in Danish and recorded with the teachers' consent. Participant details are given in Table 8.1, and procedure details are given below for each method.

Table 8.1: Participants' details

Test setup	Participants	Schools	Grades	Subjects	Location	Time
One-on-one interview	5	5	6–9th	Math, Science	Aarhus, Aalborg, Horsens	1–1.5 hrs.
Focus group	25	12	6–9th	Math, Science	Aarhus	1 hr.

One-on-one interview procedure:

Interviews are considered a core method for eliciting requirements [167]. We conducted interviews to get the perspective of teachers in using sensors as part of school subjects, to identify problems in using existing sensors, and to determine how teachers can promote the frequent use of sensors for data-collection activities as part of teaching assignments. During the one-on-one interviews, questions were asked about how often teachers worked with sensors, what were the associated opportunities in using sensors as part of school activities, which types of sensors they used, and in which subjects they used sensors to collect real data. We asked about the various challenges they faced in using existing sensors and what attributes they thought were essential for curricula-compatible sensors.

Focus group procedure:

Focus groups help gather in-depth details about a group's actions, thoughts, and feelings, as participants can interact and converse with others while discussing a topic [168]. In our case, the focus group was a mix of teachers of different subjects (math, science, geography) and grades (5–9). The main aim was to investigate the use of sensors as an educational aid in schools, the curricula-compatible sensor classes that could facilitate secondary education in school subjects, and what specific attributes could make these sensors curricula-compatible. The meetings started with a short (10-minute) presentation about the possibilities of using sensors in everyday teaching in schools rather than just in laboratory assignments. Afterward, the teachers participated in open discussions and discussed different aspects of sensors to be used in schools, sensor classes, and their attributes required for use in education. They also provided their responses in a posttest questionnaire (see Appendix A) about how often they used sensors in their teaching plans, which parameters they normally measured using sensors, and in which subjects they used sensors.

R2: Proposing requirement models for curricula-compatible sensors

In the second step R2, we tested curricula-compatible sensor classes as well as their attributes as classified by teachers in science subjects with students aged 11–15 years. The aim was to identify further requirements important for sensors' use in an educational setting, i.e., under specific conditions indoor and outdoor. To achieve the aim we used the following method. We ran pilot tests both indoors with 24 students and outdoors with 30 students to identify the requirements and challenges in using sensors as a tool to collect, analyze, and interpret data. Table 8.2 shows the participants' details. The pilot tests were conducted in Danish and recorded with the student's consent.

Indoor pilot test procedure:

Indoor pilot tests were conducted at two different schools in 7th and 9th-grade science lessons. For the indoor pilot tests, the teachers designed ac-

Table 8.2: Participants' details in pilot tests with students

Sr. No.	Test Setup	Participants	Grade	Subject	Location	Duration
Pilot test 1	Indoor	16	9	Science	Aarhus	6 hrs.
Pilot test 2	Outdoor	16	9	Science	Aarhus	3 hrs.
Pilot test 3	Indoor	8	7	Science	Aarhus	3 hrs.
Pilot test 4	Outdoor	14	8	Science	Aarhus	3 hrs.

tivities as part of science subjects in which students used temperature, pressure, and light sensors. The students collected data inside the classroom, such as light intensity under different conditions, e.g., with open and covered windows. They also recorded room light intensity and studied what light intensity levels were optimal for the classroom reading environment. Environmental sensors were also used to analyze how the classroom environment changed under different conditions, e.g., humidity, temperature, etc. Using temperature sensors, the students recorded classroom temperature at different locations and found the minimum and maximum temperature values. We used the observation method to identify difficulties when students worked with these sensors. Afterward, the students also answered a posttest questionnaire (see Appendix B) with both open-ended and closed questions regarding working with sensors.

Outdoor pilot test procedure:

The science teachers for 8th and 9th-grade students designed outdoor tests. The students went outside the classroom and collected data using temperature, light, pollution, and pH sensors. They also used an application for recording noise levels. Students recorded the temperature of stream water, checked its quality, and measured the light intensity under the shade and in direct sunlight. The students were very engaged, performed tasks in teams, and answered a questionnaire prepared by the teachers. Afterward, they also answered a posttest questionnaire (see Appendix B) with questions about the use of sensors and the data collected.

4 Results

In this section, we discuss the results obtained at research steps R1 and R2. Overall, the teachers agreed that learning could be strengthened using sensor technology that enables students to directly relate the subject to their surroundings. In general, teachers use sensor technology with secondary school students in physics, chemistry, and biology, particularly in technical experiments.

The teachers acknowledged that sensor technology and data collection activities are beneficial for elementary and secondary school students. However, they pointed also to challenges in the frequent use of existing sensors to facilitate educational activities, for instance, lack of resources, the extra time required to design activities, and unawareness of the possibilities that sensor technology can offer in teaching practices. There are also some barriers present due to the cost and maintenance of the sensors. Further in this section we discuss the following issues that yielded the main results of the study:

- The role of sensor technology in schools,
- Curricula-compatible sensor classes,
- Criteria for curricula-compatible sensors,
- Mapping to existing sensors,
- Requirements for curricula-compatible sensors under specific conditions.

4.1 The role of sensor technology in schools

Using one-on-one interviews and the focus group meeting in research step R1, we identified teachers' perspectives about integrating sensors as an educational aid to collect and analyze data as part of their subjects. Figure 8.2 represents how often teachers used sensors in their teaching plans. Most teachers used sensors to perform specific science experiments, but they also liked the idea of using sensors as educational instruments as part of everyday teaching to provide a hands-on experience to students and to relate the subjects to real data. According to the teachers, using the opportunities shown in Figure 8.3, students will learn more from the experience and retain more information about a topic, as sensors provide a hands-on experience in this regard and make the subject more interesting; also, students will participate more in discussions and understand better how data is generated, analyzed, and interpreted.

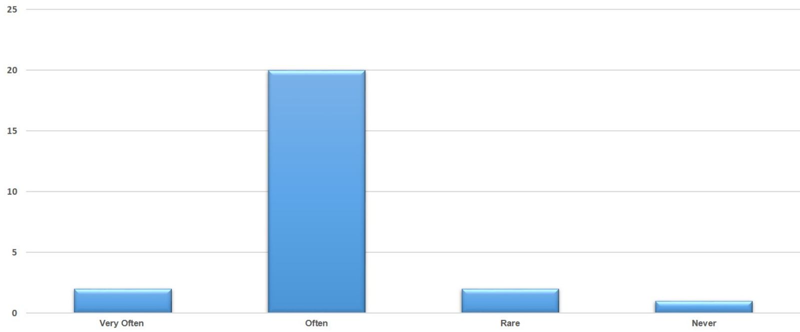

Fig. 8.2: Teachers' frequency of use of sensors in teaching activities (the number on the Y-axis represents the number of teachers who responded to the focus group posttest questionnaire N = 25)

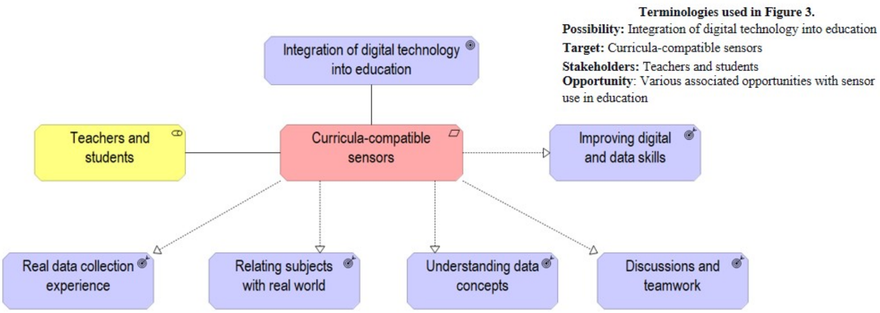

Fig. 8.3: Associated opportunities with sensor use in education

Figure 8.3 represents various opportunities associated with sensor integration into schools according to the teachers' feedback during interviews and the focus group meeting.

4.2 Curricula-compatible sensor classes

Table 8.3 shows the list of sensor classes with specific measuring properties that could easily be integrated into schools to collect data and give benefit to student learning in different subjects, e.g., measuring temperature, quality of light, etc. These classes were identified by teachers during one-on-interviews and focus group open discussion session. Each class is briefly discussed below:

- **Temperature sensors:** A temperature sensor [189] is used to measure the amount of energy in the form of heat and cold produced by an

Table 8.3: Curricula-compatible sensor classes identified from the one-on-interviews and focus group meeting

Educational sensor classes	Measuring properties
Temperature sensors	Temperature, warmness, heat current, etc.
Sound sensors	Sound, changes in sound pressure level, etc.
Light sensors	Intensity of light, wavelength, polarity, etc.
Pressure sensors	Pressure, force, etc.
Environmental sensors	Humidity, air quality, CO level, etc.

object and a system. Temperature sensors make it possible to detect any physical change to that energy and give the output as an analog or digital signal. According to teachers, these sensors can attract students' attention in both science and math, e.g., they can measure the indoor temperature at different time intervals and can arrange data in tables and present the results.

- **Sound sensor:** A sound sensor is used to detect the intensity of sound. It converts the acoustic wave into an electrical signal output. Students can, e.g., use these sensors to monitor sound levels and note the noise level in the classroom.

- **Light sensor:** A light sensor is a photoelectric passive sensor that changes light energy into an electrical signal output. Light sensors can measure the ambient light, e.g., surrounding light, room light, and reflected light. Students can use the sensors to measure light intensity, quality of light, etc. to understand these abstract concepts using real data.

- **Pressure sensor:** Pressure is an external force exerted on a surface in unidirectional areas. In schools, generally, students can measure the pressure of a liquid, air, and other gases as part of a physics lesson, and pressure sensors can help students to understand the concept of pressure in a real setting.

- **Environmental sensor:** These sensors can be used, e.g., in classrooms to measure indoor climate, such as air quality, humidity, CO level, etc.

Figure 8.4 presents the list of educational sensor classes and their properties that could facilitate school subjects by relating real data to their respective subjects. The properties are also identified from the response of 30 teachers during one-on-interviews and focus group meeting. school subjects by relating real data to their respective subjects. The properties are also identified from the response of 30 teachers during one-on-interviews and focus group meeting.

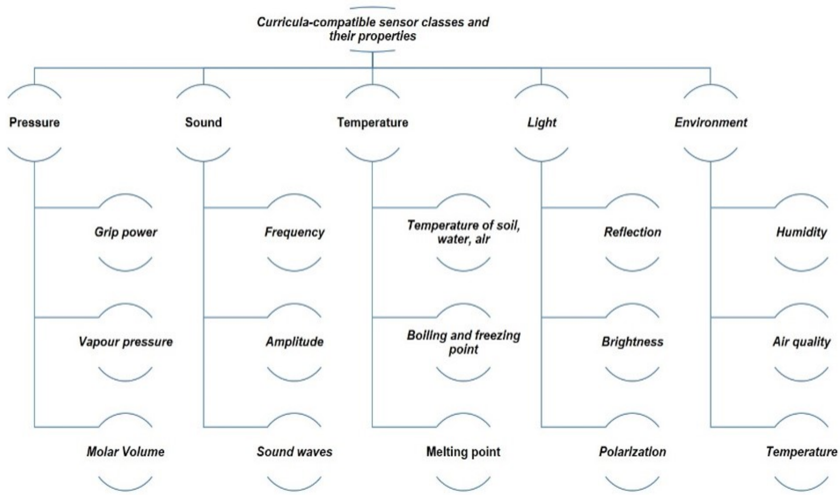

Fig. 8.4: Curricula-compatible sensor classes and their properties (N=30).

4.3 General criteria for curricula-compatible sensors

While different sensor classes have their specific properties, in this research we were interested in criteria, which could be applied to sensors in general. We define curricula-compatible sensors as those sensors that can help with educational activities in the classroom. The key parameters that concern the generic characteristics of the curricula-compatible sensors, e.g., accuracy, safety, and so on, are referred to as curricula-compatible sensor attributes, and the corresponding values are referred to as attribute values. The attribute criteria for curricula-compatible sensors refer to the set of specific rules that attribute and their corresponding attribute values must satisfy. Curricula-compatible requirements are defined as the attributes that sensors must possess in order to be considered curricula-compatible sensors.

To define general criteria for curricula-compatible sensors, various attributes were selected from the literature [181, 190, 191] and verified with teachers during one-on-one interviews and the focus group meeting. A list of various attributes was presented to teachers during one-on-one interviews and focus group meetings. Teachers chose attributes that they believed were important in an educational setting in open discussion during focus group meeting. Figure 8.5 represents the identified attributes required for curricula-compatible sensors according to teachers' responses. All of the listed attributes in Figure 8.5 are important in an educational setting, but some are more significant than others. For instance, safety and ease of handling are the

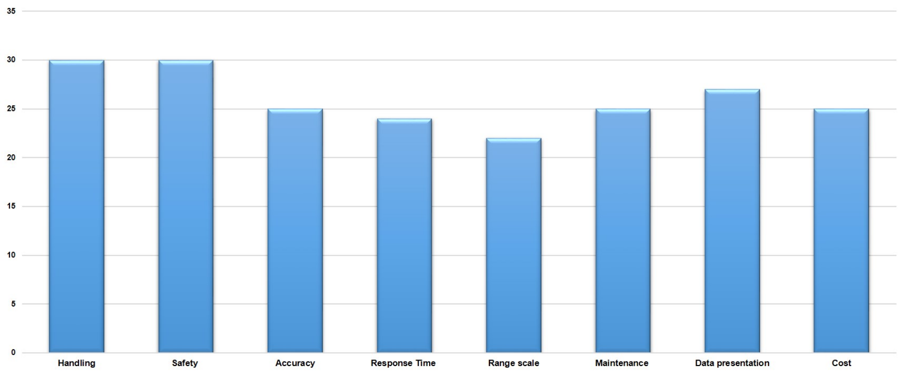

Fig. 8.5: Teachers' perspective on sensor attributes where the Y-axis represents number of teachers participated in the focus group and one-on-interviews (N=30).

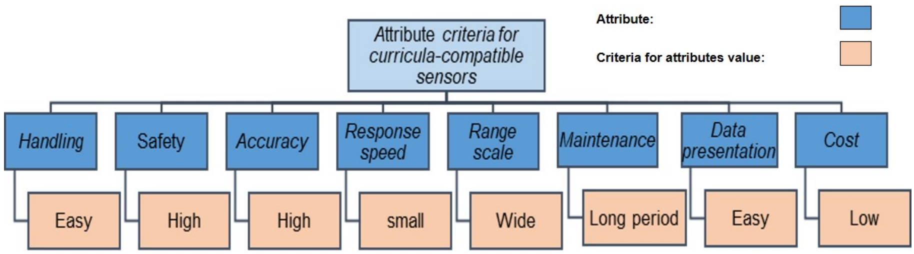

Fig. 8.6: Curricula-compatible attributes and criteria for corresponding attributes value.

main attributes that a sensor must have in order to be used in an educational activity. Furthermore, data representation software for curricula-compatible sensors is required for data to be easy to understand. The other attributes also have significance when working with students, such as response time, accuracy, range scale, and maintenance, as students can easily divert their attention if, e.g., the response time is too long.

Figure 8.6 represents the obtained set of sensor attributes and the corresponding criteria for sensor attributes value, in general, for being used in educational activities, based on teachers' feedback during one-on-one interviews and the focus group meeting. The identified attributes are briefly described below:

- Handling: To integrate sensors into schools, students and teachers must use them without difficulties. According to the teachers' feedback, students will pay more attention to data-collecting activities rather than investigating how to use the sensor if the design of a sensor is simple.

- Safety: The teachers recognized safety as an important attribute for curricula-compatible sensors. For students aged 11–15 years, sensors must fulfill the criteria for curricula-compatible sensors. For instance, in case of damage or accident, sensors' safety attributes must be high. Hence, the material, design, and shape of a sensor must be harmless under any conditions.

- Accuracy: Accuracy is an important characteristic in sensors and is calculated in terms of the error in measurement and defined as the difference between the measured value and the true value of a measured parameter [192]. For a sensor to be curricula-compatible, it must measure value to an extent that allows students to relate real values of a parameter to their collected values. Teachers suggested that, if the measured value is close to the actual value, it would help to retain students' attention; otherwise, students may lose interest.
- Response speed: According to teachers, for data-collection activities in schools, response time should be minimal for a curricula-compatible sensor.
- Range scale: The range scale is the difference between the maximum and minimum values of the sensed parameter. For a sensor to be used in education, it should have a wide operating range and good accuracy over the range.
- Maintenance: For a sensor to be used in education, it must require minimal maintenance over a long period of time.
- Data presentation: Software for data presentation and analysis must be simple and easy to use by both students and teachers.
- Low cost: The sensors must be affordable so that the sensors can easily be used in educational activities as part of everyday teaching.

4.4 Mapping curricula-compatible sensor criteria to existing sensors

Under this theme, existing sensors used in schools were identified and listed during the focus group meeting. We tested these sensors to determine whether they fulfilled the criteria of curricula-compatible sensors under different conditions, i.e., indoor and outdoor. During the indoor (24 students) and outdoor (30 students) pilot tests with students of 7th, 8th, and 9th grades, the students tested the sensors given in Table 8.4. The tasks were designed to test the curricula-compatible sensor attributes classified by teachers.

Table 8.4: Matching attribute criteria for curricula-compatible sensors with sensors (sensor classes) already available in the market

Existing Sensors	**Handling**	**Accuracy**	**Response**	**Cost**	**Range**	**Software**	**Suggested adjustment for curricula- compatible sensors**
Temperature sensors	Easy	High	Quick	Low	Wide	Simple	Fulfilled criteria
Barometers	Difficult	High	Quick	High	Wide	Difficult	Cost should be adjusted and handling and data presentation should be simplified
Light sensors	Easy	Moderate	Quick	High	Wide	Difficult	Data presentation should be simpler, and cost should be adjusted
Indoor-environment sensors	Easy	Moderate	Slow	High	Limited	Simple	Response time and cost should be adjusted
Sound sensors	Easy	Low	Quick	High	Wide	Difficult	Cost should be adjusted
Microphones	Easy	High	Quick	Low	Wide	Simple	Fulfilled criteria
Outdoor environment sensors	Easy	Moderate	Slow	High	Limited	Simple	Cost should be adjusted

Most of the existing sensors are expensive and sensitive when satisfying the other criteria such as handling, simple data presentation, etc., and, therefore, do not fit well to be used as a tool for school activities. The safety and maintenance attributes of sensors are not represented in Table 4 because most existing sensors meet the criteria corresponding to them. Teachers used these existing sensors in laboratories with great caution, and the students did not get a chance to explore data-related activities in an independent environment. We discovered that the sensors' attributes were either directly or indirectly related with each other; for instance, if a sensor satisfied the criteria for handling, safety, and accuracy, then the criterion for cost was not fulfilled. For instance, the cost of sensors that are easy to handle, safe, and have high accuracy is much higher than of one with low accuracy and easy handling. However, the attribute values could be adjusted in existing sensors to transform them into curricula-compatible sensors. For instance, the high cost of environmental sensors can be adjusted by providing only the features that are useful for school teaching instead of those for professional use, such as accuracy up to two decimal places.

4.5 Requirements for curricula-compatible sensors under specific conditions

The criteria defined above represent general attributes that curricula-compatible sensors must have; however, there are some specific requirements sensors must have to be considered as curricula-compatible sensors under specific conditions, such as indoor and outdoor. These requirements were identified during pilot tests with students and are discussed below.

Indoor:

To identify the requirements for indoor use of sensors in schools, we used wireless temperature, light, and pressure sensors. We chose these sensors as they were frequently used by teachers. We observed students during the tests, for instance, how they handled the sensors, what difficulties they faced while working with the sensors, and their data-collection activities. The model shown in Figure 8.7 describes the requirements we identified during the two indoor pilot tests at different schools in the 7th and 9th grades. The students also answered a short online survey with questions focusing on various problems they faced. For instance, students faced difficulties in connecting the sensors to data-analytic software. For light sensors, the students recorded different data under the same circumstances. It was difficult for them to understand which data were correct and why they had different data recorded by the same sensor. Furthermore, teachers emphasized the need for a flexible

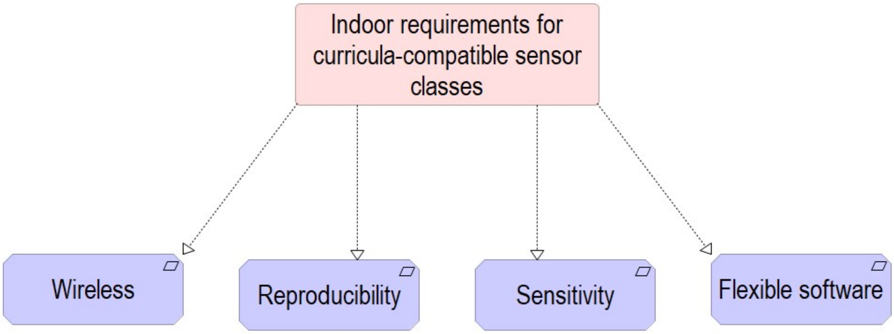

Fig. 8.7: Requirements for indoor curricula-compatible sensors.

data analysis software that collects data from various types of sensors and is simple to install.

Outdoor:

One of the main requirements identified during the pilot tests with students (grades 8 and 9) concerned the environmental conditions while collecting data outside the building. The students used light sensors, pollution sen-

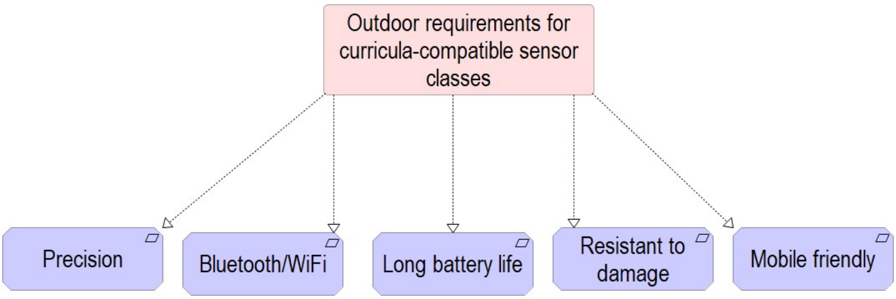

Fig. 8.8: Requirements for outdoor curricula-compatible sensor classes.

sors, pH sensors, and a noise application for data collection. According to teachers' feedback during the focus group meeting and observation during outdoor tests, the students faced difficulties in collecting data due to environmental factors such as temperature, corrosion, pressure, etc. Environmental conditions were the main factors that affected the input and output stimuli of the sensors. Noise also affected the output signal of the sensors in some cases. Therefore, for sensors to be curricula-compatible, the performance and long-term stability of the sensors should be considered for extreme conditions so that these factors do not create adverse effects during the data-collection activity in schools. Figure 8.8 represents a requirement model for the outdoor use of sensors. Teachers also suggested that if the sensors could connect and send the collected data to any device or application compatible with mobile phones, it would make the data collection process simpler.

5 Discussion and conclusions

In this paper, we studied how sensors can facilitate the understanding of data and working with real data as well as how curricula-compatible sensors should be designed. Sensors are useful for incorporating computing and technology into the curriculum for school students. Using sensors in the classroom helps to bring science lessons to life and builds confidence in using technology that is not typically found in the classroom. We learned, that existing sensors have some barriers to their frequent use in schools; for instance, if safety and easy handling are of main priority, then the cost is high. Also, in some cases, the data presentation software was not compatible with the school computer system. This study was limited to only some schools in Denmark. Nevertheless, it provides school administrations and teachers with an overview of why and how to integrate sensors into school education. For instance, the criteria enable teachers to consider the various attributes essential for sensors before choosing a sensor for a subject. The results of the study also enable manufacturers to build sensors that meet the criteria defined in this study for educational purposes. For instance, high professional quality is not required for sensors to be used in education; rather, they must have certain attributes that should meet the criteria for curricula-compatible sensors. The analysis of related work, sensor specifications, the results of five teacher interviews, the focus group (25 teachers), and four pilot tests (two indoor tests with 24 and two outdoor tests with 30 students) led to the following conclusions:

1. The use of sensors in schools can facilitate the understanding and handling of real data in the following ways:
   - It allows students to work with real data collection,
   - It helps to relate teaching subjects to the real world,
   - It supports the understanding of the concept of data,
   - It promotes decision-making and teamwork,
   - It improves the digital skills of students.
2. Five relevant curricula-compatible sensor classes are identified, i.e., temperature sensors, sound sensors, light sensors, pressure sensors, and environmental sensors, that could facilitate educational domains in developing digital and data skills among school students.

3. Curricula-compatible sensors should have the following attributes: easy handling, high safety, high accuracy, moderate response speed, a wide range scale, easy maintenance over a longer period, easy data presentation, and low cost. Further analysis of different classes of available outdoor and indoor sensors made it possible to define specific requirements for curricula-compatible sensors that are amalgamated in two requirements models. The results of the sensor analysis also showed whether adjustments are needed to existing sensors to apply them in school curricula. We found that, at present, only temperature sensors and microphones fulfill the criteria for curricula-compatible sensors.

The findings reflected in this paper are useful for understanding current possibilities and identifying which future developments are needed regarding the integration of use of sensors into school curricula. Based on the findings of this study, our future research will focus on how to combine sensor data collected during educational activities with open educational data sets to facilitate engaging teaching assignments in schools.

6 Acknowledgement

We acknowledge stakeholders' contribution to this research work, including the Community Drive project and Aalborg University for providing funding, Danish public schools, teachers, and students. We also acknowledge the valuable comments of the anonymous reviewers of this article.

7 Appendix A

Questionnaire on the use of sensors in schools to collect data (Translated from Danish)

Personal Information

School name:

Gender:

Age:

Experience:

1. What grade levels do you teach?

2. What pedagogical approaches do you use in your teaching and how much?

- Traditional direct instruction
- Teaching with experiments
- Collaborative learning

3. Have you ever used sensors or technology (e.g., mobile applications, trackers) in your teaching activities?
    - Yes
    - No
4. To what extent do you use sensors in teaching?
    - More often
    - Often
    - Rare
    - Never
5. What parameters do you measure with sensors in your teaching activities most often?
    - Temperature
    - Pressure
    - Light
    - Sound
    - Position
    - Motion
    - Environmental parameters e.g., CO, moisture etc.
    - Other
6. Are the currently used sensors and associated software easy to understand and use by both you and your students? Briefly explain your answer.
7. How sensors use can be made easy in educational activities, i.e. easily used by students and teachers (simple graphs, sensors design or shape)?
8. Are some school subjects better suited to the integration of sensors than others? If so, which ones?

8 Appendix B

Pilot Test Survey 2020 (Translated from Danish)

School name:

Grade:

1. Which of the following methods do you like best when collecting data?
   - With notebook
   - With sensors
   - With mobile application
2. Do you like working with sensors and technology?
   - Yes
   - No
3. What is difficult when working with sensors?
   - Set up the sensor
   - Software
   - Understand graphs
   - Understand data
4. Is the light sensor easy to use?
   - Yes
   - No
5. What difficulties do you encounter when working with sensors, such as the software, graphs, or the sensor itself?
   - I do not know how to use the sensor without the help of the teacher
   - Connecting the sensors to software is difficult
   - You must be very careful when using sensors
   - Other (please specify)
6. Do you need help all the time when working with sensors?
   - Yes
   - No
7. Did any problems occur while working with the temperature sensor, such as the sensor not responding or collecting the correct data?
   - Yes
   - No

If so, please mention

8. What parameters do you like to measure using sensors?

    - Noise
    - Temperature / heat / cold
    - Physical activities
    - Air quality
    - Other things

Chapter 9

Paper 6: Digital innovation in education: Perspectives, opportunities, and challenges of educational open data and sensor data

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Abstract

The emergence of digital technologies and data has influenced every area of life, from business to education. Data are important not only for global economic growth, public services, and social change but also for education. To address the challenges of the digital shift, the ability to interpret data and make decisions based on those interpretations is becoming increasingly important for our younger generation. It will be imperative for future generations of students to be equipped with the necessary digital and data skills to face the challenges of a digital and data society. This paper will discuss the perspectives, future opportunities, and challenges of using educationally relevant open data and sensor data in schools to create new possibilities for digital and data innovation in secondary school education.

Keywords

Open data; sensor data; digital and data skills; digital innovation.

1 Introduction

Data and digital technologies are now entrenched in our daily lives. It is therefore vital for young learners to be equipped with digital and data skills, the ability to understand data, and a command of digital technology operation [156]. There has been a rapid increase in openly accessible data sources that can be used without permissions and restrictions, such as open data that are publicly available data sets about traffic, population, education, the environment, statistics, etc. [10]. Simultaneously, with advancements in sensor technology, using sensors for data collection activities is now widely available to schools to integrate into their curricula [193]. Sensors can play an important role in education [194], particularly for secondary school students, as students begin to consider their surroundings, including the various phenomena occurring within those surroundings. Sensors can provide students with new types of hands-on, real-world experience in their immediate surroundings [178]. Furthermore, incorporating IoT and sensors in the educational sector can provide students with hands-on experience with digital technology. It can also aid at the beginning of a process of sustainability perception and attitudinal shift among young students. For instance, authors in [195] discussed how IoT-enabled energy applications, for example, could be integrated into school life. The findings show that IoT and sensors can provide educational and energy-saving benefits by engaging students and providing them with hands-on experience based on real-world data.

Open data and sensor data can both play key roles in bringing digital innovation to education by engaging students in data collection activities and allowing them to understand the concept of data via analysis and interpretation in relation to the real world [13,180]. To build a digital and data-literate society, it is essential to initiate the acquisition of key data literacy skills early in education (fifth grade onward). For instance, how data is collected, published, and used in real life and what data platforms can be used to access educational relevant data sets. The scant research on the use of open data in elementary or secondary schools indicates a lack of awareness among educators [17]. Notably, there are challenges in integrating digital and data technology in schools, such as teachers being unaware of open data, including its potential as an educational resource, and the need for skilled teachers to integrate well-suited data into their teaching assignments.

Previous research studies [19,61,108,153,194,196] conducted in close collaboration with Danish public schools identified opportunities for open data as an educational resource. For example, the use of data from students' municipalities can pique their interest, foster discussions, and explain problems in students' geographical or social environments, which helps them relate the data to their everyday lives [19]. Several issues that impede teachers' use of open data in education have also been recognized, such as the concept of open data being abstract and difficult for students to understand and the fact that hands-on data collection activities are required to grasp the concept of data [61]. To aid teachers, educational open data domains were identified from the national open data portal, and an open data interface was developed to assist with educational assignments using educationally relevant open data sets in a previous study [153]. Additionally, requirement models for curriculum-compatible sensors were developed for data collection activities and usability of open data interface has been tested by teachers and students [194,196].

However, to take full advantage of these publicly available resources, further research is needed to better understand the value and opportunities of open data as an educational resource, including how to integrate real data sets into the learning process. This exploratory paper will explore the perspectives and future possibilities of using open data in education in a variety of contexts other than classroom activities based on our previously conducted research studies [19,61,108,153,194,196]. We will discuss the perspective of open data and sensor data in a broader view in the following research question (RQ):

RQ: (a) What are the future opportunities for open data and sensor data in an educational context, and (b) what are the potential challenges to realizing these opportunities?

The following is the structure of the exploratory article. The research methods for identifying challenges and opportunities are presented in Section 2. Section 3 presents the results and in Section 4, the conclusions are presented. Finally, the limitations and future research are discussed in Section 5.

2 Research method

In this exploratory research work, we reviewed our previous work [19,61,108, 153,194,196] to comprehend and analyze the future challenges and opportunities associated with the use of open data and sensor data as educational resources. Previously, we discussed open data and sensor data usage in separate studies [19,108,194,196], identifying the benefits and existing challenges of open data and sensor data usage in school education, as well as proposing solutions to these challenges. In this study, however, we analyzed the overall data collected (in close collaboration with both teachers and students) in previous research studies to identify future challenges and perspectives for both open data and sensor data in school education. The overall data (collected in previous research studies) were categorized into three broad categories: future opportunities associated with the use of open data and sensor data in an educational context, challenges in using open and sensor data, and initiatives to reap the benefits of open data and sensor data in education. Table 9.1 provides a summary of the participants and research methods used in our previous research studies.

Table 9.1: Overview of the participants and research methods used in previous studies [19,108, 194,196] for data collection.

Research study	**Participants**	**Methods**
Research study 1 [108]	10 teachers and 21 students	One-on-one interviews and pilot test
Research study 2 [19]	10 teachers and 12 students	Open discussion, online questionnaire, observations
Research study 3 [194]	30 teachers and 38 students	Focus group, one-on-one interview, pilot test (indoor and out door)
Research study 4 [196]	39 teachers and 16 students	Focus group, one-on-one interview, pilot test, online usability test

The following steps comprise the research methods used in this work:

1. Analyses of previous work in the educational domain, including the

use of open data and sensor data in tandem.

2. Identifying future challenges and opportunities for the use of open data in education.

3. Proposing initiatives to mitigate the barriers to the use of open and sensor data in education.

In the following section, the research results are briefly discussed.

3 Results

In this section, the main findings are discussed under the following categories:

1. Future opportunities for open data and sensor data use in an educational context

2. Challenges in using open and sensor data in education

3. Initiative to reap the benefits of open data and sensor data in education

3.1 Future opportunities for open data and sensor data in an educational context

Many institutions have already recognized the importance of involving schools and higher education institutions in open data research [35,174]. Open data are an excellent resource for gaining hands-on experience with techniques and tools for searching, cleaning, and organizing data, whether by hand or with computers [157,158]. Open data also impact subject learning, the development of digital and data skills, and even student motivation to learn by relating the subject to the student's environment. For example, Discover Kells[1] uses open data from the National Monuments Service and the National Inventory of Architectural Heritage of Ireland and provides information about national monuments and historical buildings. These data sets can be used in history topics to make them more interesting.

However, to reap the full benefits of open data, governments or educational administrators must also be involved in incorporating educational open data directly into educational plans. For example, secondary education plans could involve an introduction to basic data principles, such as structures, formats, and analysis. These kinds of measures are critical if we want to encourage students towards more active learning using open data. Norway[2] and the United Kingdom [157] have already launched projects with

[1]https://data.gov.ie/showcase/discover-kells

[2]https://site.uit.no/opendatainteaching/

a particular focus on data literacy in elementary schools with positive results. However, when working with publicly available data sets, consideration should also be given to data privacy and ethical use [197].

Sensors, on the other hand, can be useful in understanding the concept of open data. For example, students can collect pollution data near a railway station using sensors and compare them to available open data. This allows the students to understand how data are generated and what factors may influence the data collection process if there are differences between the sensor data and the open data. These types of activities expose students to real-time data collection activities outside the classroom [198]. They can better understand sensor data when it is collected in real-time and generally small in size. Using open data as an educational resource provides students a better sense of their surroundings, cities, and country. Sensor data, such as classroom temperature, humidity, pollution level, noise level, etc., can be shared with other schools by uploading them to a common platform.

Students can also compare their school data with those of other schools rather than with those of their immediate surroundings or cities. For example, they can reflect on why their school's noise or pollution levels are higher than those of other schools. Students may develop a wide range of skills through these activities, ranging from the use of complex technologies and the ability to analyze and argue to the development of vital skills, such as teamwork, critical thinking, and discussion. Figure 9.1 shows how sensor data relate to educationally relevant open data sets and existing national open data sets.

Figure 9.1 represents how educationally relevant open data sets, for example, can be identified and selected for use in education as part of school subjects. Simultaneously, using sensors, some educationally relevant data sets can be collected locally (in school surroundings) and made available to other schools via a common educational open data platform. They can gain a better understanding of the concepts of open and private data. For example, sharing collected data with others or avoid exposing data to others in certain activities.

Without systematic planning, integrating open data as an educational resource will not yield the desired results. Systematic planning may include teacher training, access to additional resources, such as sensors in schools, and a shift from the traditional teaching methods toward more collaborative and problem-based learning methods at the school level. A common platform that could relate relevant educational open data sets to school subjects and allows students to share data collected during various educational activities using sensors or other technologies within or outside school could also be beneficial. These tasks will not only benefit teachers and students but will also enhance learning environments and citizen science.

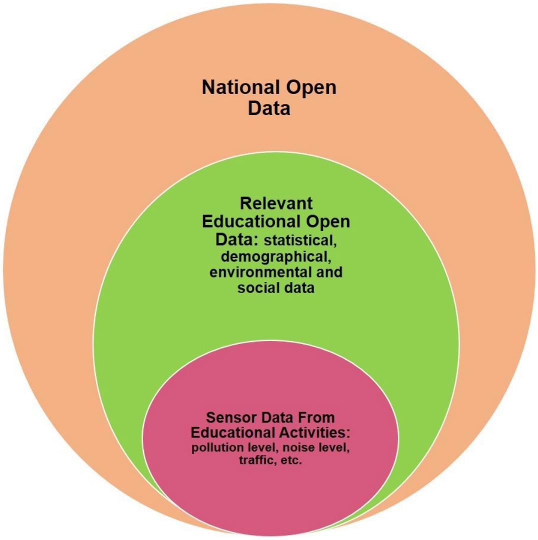

Fig. 9.1: The relation of educational open data and sensor data (collected through school educational activities and made available for other schools) to national open data (inspiration from [199]).

3.2 Challenges in using open and sensor data in education

In this section, we will discuss the future challenges (that still need to be addressed) that may influence the use of open data and sensor data in educational activities. Generally, open data research is concerned with the data type, quality, structure, and design of real-time applications to access and publish data sets. However, there has been less emphasis on developing tools or applications that can make these data sets more accessible and usable for students [151]. Access to relevant educational data sets as an educational resource has been identified as a major challenge in previous studies [153]. This issue still needs to be addressed at the national level in the future. A national educational open data portal that not only provides access to relevant educational data sets from various cities but also visualizes these data sets in the form of interactive graphs, could benefit teaching and learning processes in a broader sense. Different cities publish different themes of open data sets based on their geographical and demographic backgrounds that can be useful in an educational setting. For instance, Table 9.2 shows the main open data themes of various Danish cities. Each city has different data sets themes based on its historical background, location, and population. For example, Copenhagen, the largest city with the highest population, mostly has data sets about traffic, the environment, noise, etc., whereas Vejle has also data sets about floods due to its location, as well as other data sets such as

Table 9.2: Open data sets of various cities in Denmark City.

City (inhabitants)	No. of Data sets	Main Data sets
Copenhagen (638K)	288	Transport, environment, districts, education, population, tourism
Aarhus (283K)	123	Education, traffic, population, bicycles, sensor data, tourism
Vejle (59K)	99	Floods, education, bicycles
Odense (181K)	30	Culture, education, transport

education [3]. This information of different cities could also be interesting for students both for quantitative and comparative studies.

With access to educational relevant data sets of different cities, students can further learn how the demands and services of cities can vary depending on their population and geographical location. In an educational setting, applications that allow students to access, use, and share their own data (collected during various educational activities) are also required. Previous studies have also shown that it is critical for students to have access to up-to-date data sets when working with real-world data sets [153] and this issue must also be addressed in future studies.

Another challenge that could affect the successful use of open data and sensor data is teachers' motivation, instructional design, and training. One possible solution to motivate teachers could be sharing success stories through national educational open data platforms. Awareness can also be spread by setting up small competitions based on data. These would not only involve students but also motivate teachers to learn more about data-related activities. The associated learning skills are not achieved simply by using open data in school teaching; they are also dependent on how open data is used pedagogically, and this requires revision in schools' curriculum strategies. When working with data and technology, ethical, privacy, ownership, and legal considerations need to be reviewed, such as copyright, authorship, and content. It is also important to teach students about the ethical use of data when they publish on common platforms (i.e., use correct information).

[3]https://www.opendata.dk/

3.3 Initiative to reap the benefits of open data and sensor data in education

The following measures must be implemented in the future to reap the maximum educational benefits from open data and sensor data use in the educational domain.

1. Providing schools with access to relevant up-to-date educational data
2. Providing schools with access to curricula-compatible sensors and technology in an educational context
3. Developing a national educational open data platform that provides access to existing relevant educational data sets and allows the educational community to share their experiences and publish data collected through educational activities
4. Training and awareness programs for teachers
5. Involvement of government or educational administration in open data initiatives

4 Limitations and future research

The results presented in this research study are limited to schools (teachers and students as participants) in Denmark. However, it provides the educational community an overview of the possibilities, opportunities, and challenges in using open data and sensor data in educational activities. To fully exploit the benefits of open data and sensor data, research is needed to discover ways to successfully integrate open data and sensor data in curricula and develop a common platform that allows the teaching community to share their success stories and upload the results of data collection educational activities for others. The organization of seminars or courses is also required to increase the awareness of and motivation toward the use of open data among teachers. Lastly, there is a need for government or administrative involvement in successfully integrating open data into the school system.

The value of open data and sensor data in the learning process has not been sufficiently investigated to date; therefore, more investigations are needed to reap the full benefits of open data and sensor data in future research. To successfully integrate open data and sensor data learning into schools and gain the full advantage of open data opportunities, the initiatives and challenges discussed above need to be addressed.

5 Conclusion

With the introduction of technology in schools and a push for more accessible government data, there are many opportunities for better data collection and analysis in education. One way to assist students in developing digital and data skills is the use of open data in the classroom as an instructional resource. The literacy of these skills has become vital in the early stages (e.g., secondary school) of education to build a strong, informed, and talented workforce that is ready to face future challenges and opportunities.

The availability of open data has many associated opportunities from not only a technical or governmental perspective, such as improving public services and bringing transparency to government policies but also from the educational perspective, such as using open data as an open resource to help students learn essential future skills and provide a learning environment that allows students to relate their subjects with their immediate surroundings. Open data and sensor data also provide students with information that, in some cases, requires significant time and effort to accomplish a task or draw a conclusion.

Part III

Conclusion and future work

Chapter 10

Discussion and conclusion

Because this dissertation is a collection of papers, Chapters 4–9 are self-contained, and the reader is directed to the overall conclusions in the last portion of those chapters. The following is a synopsis of the two main research topics; open data and sensor data use in education. The synopsis highlights only the most important contributions and conclusions.

The advent of the era of big data is profoundly affecting people's learning and lifestyles and will have a revolutionary impact on all industries. For the education field, open data can not only improve schools' educational management systems (e.g., data about grades, leaves, and performance) but can also support the improvement of various learning skills of secondary school education by integrating appropriate related data sets into different subjects. Various challenges exist for incorporating open data into schools, and strategies are needed to reap the educational potential of open data.

One possible solution to address these challenges is the development of collaborative projects where students have to search and filter information, analyze data, or generate visualizations in almost any subject. Students can gain a wide range of skills through these types of projects, ranging from the use of technological tools and the ability to analyze and argue, to the improvement of skills such as teamwork and critical thinking. Government involvement is also essential to promote more active learning using open data by integrating open data into school curricula.

In this age of data abundance, sensors play an important role in familiarizing secondary school students with the concept of data. Students can use sensor data both to analyze the experimental results of their own science subjects and to gain hands-on experience with collecting data from their surroundings and to make comparisons with the existing open data sets of their cities or schools, such as levels of pollution, noise, and traffic. Our studies have also shown that research is being conducted in the development of various types of sensors but is limited in the educational context, such as how sensors can be integrated into everyday school activities and how sensor data and open data can be used to improve students' digital and data skills.

The results obtained in Chapter 4 show the potential of incorporating open data in classrooms, such as the improvement of data and digital skills, teamwork, and critical thinking. The use of open data in the form of simple interactive visualizations can also be integrated into instructional designs as part of various teaching subjects, particularly mathematics, science, and geography. Through the relation of real data sets to school subjects, the use of these data sets can aid in improving students' learning behaviors. The identification of educational open data themes in this dissertation (Chapters 4 and 5) corresponding to various school subjects could support teachers in integrating relevant open data sets into their instructional designs and provide a perception of which open data sets could be used in pertinent educational domains.

Another challenge highlighted during this study is teachers' access to relevant educational open data sets. They need an educational platform with access to open data sets as part of different subjects in the form of simple visualizations. To address this problem, a novel method is described in this dissertation (Chapter 6) for creating an open data interface (ODI) that can aid teachers and students in their educational activities by providing easy access to educationally relevant data sets. The EAORE approach (Chapter 6) is used to identify teachers' and students' requirements for open data usage in educational activities and for the design of an ODI at the school level.

The usability tests of the ODI and educationally relevant data sets in a real-world scenario show promising results in bridging the gap between the availability of open data sets and the use of such data sets in an educational context (Chapter 7).

Data collected through sensors in a school activity could also be provided to other schools to make comparisons or to use the data in other subjects, such as mathematics, to calculate means, medians, or differences and to relate the subject to the real world. In this dissertation (Chapter 8), the focus is also on the perspectives of teachers in using sensors to understand the handling of data. A criterion is developed for curricula-compatible sensors to address this challenge. The results show that the criteria for curricula-compatible sensors enable teachers to consider the various attributes essential for sensors before choosing a sensor for a subject. These criteria will also enable manufacturers to build sensors that will meet the criteria defined in this study for educational purposes.

Although various potentials and challenges have been highlighted in this dissertation, more research is still needed to investigate open data and sensor data opportunities in education and to address the various challenges in this field as discussed in Chapter 9.

The overall conclusion of this dissertation is that in order to increase the effective use of open data and sensor data in learning, we must understand how to effectively harness the associated potentials identified in this research by designing and implementing learning activities, as well as supporting approaches and technologies that could facilitate the use of open data and sensor data in an educational context.

Chapter 11

Future work

Chapters 4 through 9 each discuss and provide ideas for future work. The most pertinent and interesting ideas involved here:

- exploring and analyzing educationally relevant open data sets from neighboring countries;
- investigating how open data and sensor data can be incorporated into the textbook and instructional design through both indoor and outdoor activities;
- investigating the use of open data interface (ODI) to combine sensor data and educationally relevant open data;
- extending the ODI to a national educational open data interface, thus allowing students to upload their own collected data (such as pollution, traffic, and noise levels and water quality) and then share and compare the data with other schools;
- exploring the development of collaborative projects in which students may search for and filter information, analyze data, or generate visualizations;
- exploring pedagogical designs through open data and sensors to reap the benefits identified during the research study;
- investigating teacher training and awareness programs in open data and sensor data use in education.

Overall, future work can take numerous potential directions. The incorporation of existing research and pedagogy into this endeavor should prove fruitful, and the analysis and development of the ODI and various requirements models for curricula-compatible sensors presented in this dissertation will provide a conceptual starting point for these efforts.

This concludes the dissertation.

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