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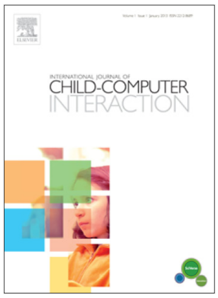

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Empowering Educators by Developing Professional Practice in Digital Fabrication and Design Thinking

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ABSTRACT

The world is becoming increasingly automated, and the ability to deal with technologies is seen as important in society and working life. Digital fabrication (DF) and design thinking (DT) have been suggested as approaches to developing students' understanding of technology and their agency in a digitised world. However, nowadays teachers are not being trained in this field. In order to prepare the next generation for a rapidly changing and unknown future heavily influenced by computing it thus seems necessary to focus on the professional development (PD) of teachers. This study investigates how development of professional practice can be conducted to empower teachers and principals to implement DF and DT activities in schools. Initially, the paper gives an overview of nine educational initiatives in the field, followed by a closer examination of the Danish FabLab@SCHOOLdk organisation. The paper identifies the different PD programmes aimed at empowering in-service teachers, pedagogues, and principals in the field of DF and DT. As the main contribution to the research community, the study identifies five important stakeholders that are supporting and operating in synergy inside the FabLab@SCHOOLdk initiative as well as the surrounding gatekeepers with influence on the development processes. The paper further illustrates how the stakeholders operate in the organisation to enable educators to apply DF and DT in schools and discusses the development of professional practice in this field. Finally, a 1:1:1 -model for realising research-based suggestions in PD programmes is presented.

Author Keywords

Digital Fabrication; Design Thinking; Education; Teachers; principals; Professional Development.

1 INTRODUCTION

The ability to deal with technologies is seen as increasingly important in society and working life. The current generation of young people seems to excel in using general technological tools such as computers and smartphones, and they are quite familiar with information and communication tools, making movies, editing photos, and creating web pages. It is alarming though that less than half of them can create something by means of exploration and fabrication technologies, such as 3D printers, vinyl cutters or fixing electronic devices [1]. How can we turn these passive consumers into critical, creative, and competent thinkers and producers – for the sake of individual '*Bildung*' and for the sake of the society?

The benefits of applying *digital fabrication in education* has been discussed by many researchers [2, 3, 4, 5]. *Digital fabrication* (DF) has been described as the next generation's 'information technology' [6]. In this study, DF refers to a variety of new digital technologies such as laser cutters, CNC milling machines, and programmable electronics, applied in explorative, creative, and reflective problem solving, and to digital manufacturing processes for designing and producing prototypes and products. DF can enhance students' existing practices and expertise, accelerate the processes of invention and iterative design cycles, allow students to engage in intellectual, long-term activities and practices, and experience new levels of collaborative work [2]. By engaging learners to combine the physical activity and abstract thinking [5] or digital tools, such as in designing electronic textiles, educators can reveal how digital media is made and designed and enhance students' abilities within problem solving and designing with technologies [4].

Lassiter et al. [7] and Smith et al. [8] have suggested that in formal education, integrating design thinking into design processes of DF can benefit students' learning. *Design thinking* (DT) is defined as the ability to thoughtfully engage in design processes and knowing how to design, act, argument, and reflect when confronted with ill-defined and complex societal problems [9].

There is a need for teachers who can provide the next generation students with adequate tools to face a rapidly changing, unknown future, heavily influenced by computing [10]. However, teachers are not trained to do that, and their inability to give students the required knowledge and competencies can make them feel unempowered. According to Smith, Iversen, and Veerasawmy [11], teachers have insufficient insight into digital technologies and tools for complex problem solving, and they consequently experience loss of authority and control of the teaching.

It has been recognised that there is a need for professional development (PD) of educators when shifting from more traditional disciplines to technological fields and providing competences for confronting and adopting constantly changing, complex processes in 21st society [7, 11, 13, 14, 15, 16]. This reveals the importance of providing education for teachers to cope with such challenges.

Hence, this paper focuses on methods for empowerment of educators to support their understanding of technologies and enable them to manage DF technologies and utilise DT processes. *Empowerment* can be defined as making people stronger, increasing their self-confidence, ability, and power to control their own life [17]. In this research, empowering teachers means to increase teachers' understanding of technologies in a way that broadens and strengthens their ability to take control of the new, unfamiliar fields of DF and DT within education and to feel confident about applying technologies in their own teaching. Consequently, the aim of this study is to investigate how *development of professional practice can be conducted to empower and support educators to apply DF and DT activities in school*s.

The study examines PD of DF and DT in education in the Danish FabLab@SCHOOLdk organisation. We pursued the aim of the study through five research questions:

1) How can educators' development of professional practice in DF and DT be conducted?
2) How does FabLab@SCHOOLdk train educators to apply DF and DT in education?
3) To what extent does FabLab@SCHOOLdk's PD programmes prepare educators to apply DF and DT in schools?
4) How does FabLab@SCHOOLdk develop a field of practice in DF and DT in education?
5) What prevents stakeholders in FabLab@SCHOOLdk from implementing DF and DT in schools?

In order to widen our perspective, we reviewed nine initiatives conducting PD activities in the field of DF and DT. To understand how the FabLab@SCHOOLdk operates, we first identified stakeholders of importance in the organisation. Second, we investigated these stakeholders' experiences and perspectives in relation to the organisation's different ways of conducting in-service teacher training aimed to empower teachers in DF and DT. Finally, we explored possibilities and challenges experienced by the stakeholders when implementing DF and DT into the education.

This study contributes to the research community, by considering the identified challenges that impede educators in teaching by means of design processes in DF [11] and by examining how the suggested framework to overcome these challenges [9] has been realised in the FabLab@SCHOOLdk. Our study revealed that it is not just a question of empowering educators, but that there is a need to consider a wider organism, where different agents support each other in order to realise and conduct systematic PD. The main contribution of this paper is the identification of the important stakeholders when applying DF and DT in schools, the considerations regarding PD in the field of DF and DT, and the discussion of the central gatekeepers' influence on the development processes.

Chapter two examines the concept of PD prior to the presentation of other existing educational initiatives. Research methods and context for empirical investigation are described in the chapter three. Chapter four contains results from the study of the FabLab@SCHOOLdk, while discussion and conclusions are presented in chapters five and six, respectively.

2 DEVELOPING PROFESSIONAL PRACTICE

2.1 Professional Development in the Field of DF and DT

Professional development (PD) can be defined as development during which individuals acquire a level of competence necessary to operate as autonomous professionals [18]. PD may be conducted through a variety of approaches, e.g. courses, consultations, coaching, communities of practises, mentoring, reflective supervision, and technical assistance.

Valid and valuable PD of teachers is recommended to be continuous, in-depth, driven by teacher needs, and linked to actual teacher practices [19]. PD may be based on different formats such as graduate classes, book studies, workshops, peer coaching, mentoring, professional learning communities, action research, inquiry models, and study groups [20]. Effective kind of PD is where teachers have time to meet, create, craft, and refine lesson plans and teaching units in team-based learning communities [21].

Earlier research identified three important challenges which impact the teachers' possibilities for integrating DF in a design literacy perspective [11].

Challenge No. 1. *Understanding of complex design processes*: According to the authors, teachers are traditionally used to goal-oriented processes where students are working with certain objects, following instructions and using specific tools and materials. They stated that teachers are lacking experience to manage open-ended design processes and find it difficult to support the students with feedback and guide them through their individual ideations and iterations.

Challenge No. 2. *Managing digital technologies and design materials*: Likewise, the authors found that teachers are lacking knowledge and competencies to handle, maintain, and run DF technologies and find it difficult to teach or advise students how to work iteratively with the technologies in order to reflect upon and develop solutions and products.

Challenge No. 3. *Balancing different modes of teaching*: Finally, the authors describe how teachers find it difficult to manage and continuously shift between different roles such as classroom teacher, facilitator of the activities in the classroom, acting as coach for the students and supporting their design processes through reflective questions and dialogues. The teachers were likewise challenged by a loss of control compared to their traditional authoritative expert-teacher role and needed new professional experience to find the courage to let go of control.

To facilitate and support co-development of new teaching practices a three-way structured framework towards training educators to acquire the capabilities identified above is suggested [5]:

1. *Workshops and lectures* using a mixture of literature on DF in education and design literature taught through lectures, group exercises, and preparatory work
2. *In-school-practice* regarding the implementation of a learning design targeted at engaging the students in creating solutions for a given challenge
3. *Peer-to-peer learning* through co-development of learning designs, structured reflection processes around the participants, and collaborative reflections in blogs

2.2 Educational Initiatives in the Field of DF and DT

This study takes a closer look at the FabLab@SCHOOLdk initiative, but in order to situate and reflect its perspectives and arguments on a broader scale, we will first provide an overview of nine other initiatives in the field: FabLearn, LTML, Maker Ed, Maker Promise, Makerskola, SCOPES-DF, TeachThought, Worlds of Making, and Fab Academy. The selection includes initiatives which provide education for supporting PD of DF and DT in K-12 education. The information regarding the purpose of each initiative, the target group they focus on, the approaches, methods, and contents they acknowledge and promote, and the focal points of their contribution in the field are gathered in table 1.

Common for the initiatives are that the education applies the principles of Jean Piaget's constructivism and Seymour Papert's constructionism in synthesis with inquiry-driven or project-based learning approach. All the initiatives conduct education both for teachers and principals. Additionally, some of them acknowledge the meaning of the administrative level in the equation, where they provide training not just for educators, but also for other supportive agents such as educational administrators at school, district, and national level, policy makers, and maker education directors and facilitators [22, 23, 25, 26, 32, 35]. To support educational development at different levels, the initiatives provide varying models of education from online resources and single workshops to year-round programmes and other long-term support systems, communities, and networking activities.

The investigated educational initiatives can be categorised according to the main substance they provide for learners. *Fab Academy* [35] is designed from the perspective of technology. It aims to provide participants with principles and applications of DF and focuses on processes and machines of DF: learning to use them, considering their advantages and limitations, and seeing different purposes for utilisation. Whereas, other initiatives are focusing on pedagogy.

Table 1. Educational Initiatives in the field of DF and DT

Initiative (Country)	Purpose	Target Group	Support/Education	Content	Method	Approach	Focal Points
PEDAGOGY-ORIENTED							
FabLearn (US) [22]	Network supports integrating making into formal and informal education: curriculum development and integration. Strategic planning, design, implementation of educational makerspace and maker education	International community of K-12 teachers, principals and maker educators, facilitators, educators, researchers, policy makers	5-day workshop 5-day classes	Learning sciences theory, instructional methodologies and pedagogy, Educational makerspace implementation Research practices, Assessment of maker-based learning Curriculum building and integration into school goals, DF tools	Combining theory and practice Inquiry-driven Project-based learning	Constructionism	Principles for hands-on learning: (1) Personal and interest driven (2) Meaningful and relevant (3) Cross-curricular (4) Holistic include curricular content, technical knowledge, cognitive and soft skills (5) Process-oriented and product-oriented (6) Moduled by teachers Developing hands-on learning should be founded on: (1) Educational research in connection with practitioners in the field (2) PD rather than purchasing of equipment (3) An international effort to achieve diversity in local focus and needs, and (4) Accessibility for all students fostering equity, inclusion, and diversity
LTML (US) [23]	Design and research centre aim to inspire and create opportunities for global collaboration and design and evaluate innovative technology-mediated solutions for learners, educators, researchers and organisations worldwide	K-12 teachers preservice teachers, coaches administrators at classroom, school, and district level	1. 1- and 2-day workshops for individual educators 2. Semester-long courses for preservice and in-service teachers and graduate students 3. Multiyear partnerships	Philosophy of making, teaching, and learning strategies. Model making pedagogy Makerspaces Technology tools, materials Computational thinking	Playful time for curious tinkering and making, reflection, sharing	Maker Movement constructivism constructionism	Put *Focus* on providing information about makerspaces and computational thinking, Apply *Fiddle* by playful time for curious tinkering and making, Value *Friends* in providing opportunities for reflection and sharing with peers [24]
Maker Ed (US) [25]	Organisation harnessing the potential of making to transform teaching and learning, and supporting educators and their organisations as they integrate maker education into daily practice	Educators institutions communities	1. Workshops 2. Self-paced online learning resources 3. Annual national convening 4. Multiyear institutional support 5. Local, regional, and national networks	Maker-centred learning Maker education programme planning and management Pedagogy Projects Spaces, tools, materials Unit plans or learning sequences, curriculum integration Documentation for assessment Leadership	Hands-on Minds-on Reflection Maker-centred learning Interactive Open-ended Learner-driven Multidisciplinary	Constructivism constructionism	Maker education is fundamentally about *approaches, mindsets,* and *community* – not about stuff. Maker Ed's focus on educators and the institutions they work in emerges from our core belief that maker education is about *people.* We know that people need support, tools, resources and community to fully participate in the opportunities offered. We know that learning is contextual and social, and that for children to get what they need, educators must have what they nee.
Maker Promise (US) [26,27]	A collaboration between Maker Ed and Digital Promise: campaign and network aim to equip schools with resources and support all stakeholders: stimulate schools to sign the promise to dedicate a space for making, to become champions of making, and display what students make	School and district leaders, educators, administrators, faculty, staff, surrounding community including families, local businesses and organisations	1. Signers gain access to an online PD course 2. Resources from partners 3. Opportunities for projects and contests 4. Meetups, summits, conventions	Constructionist approach to STEM learning, digital media, Circuit Arcade etc.	In-person connections	Constructionism	

Initiative (Country)	Purpose	Target Group	Support/Education	Content	Method	Approach	Focal Points
Makerskola (SE) [28,29]	Large-scale national testbed contributes to developing new subject-specific methodology on the creative use of new technologies	K-9 teachers principals, including special education	Evaluate methods, equipment, and logistics, and try out learning activities 1. Workshops 2. Video conferences 3. Teacher education partnership 4. Yearly conference	Maker culture Programming	Combining analogue and digital materials, and theoretical and practical work	Maker culture	Initiating and conducting projects on establishment of DF in education raised five considerations: (1) Procurement practices regarding procurement and contract difficulties (2) The teacher and leader perspectives relating to both parties' unconfident feeling in working in the new field and requesting targeted training for both sides (3) Informing national policy makers about the power of DF and making in education (4) Creating equal opportunities for all children, thus ensuring that the topic and setting of activities are interesting and attractive to many, including both genders, (5) Progression in DF i.e. the process and progression of knowledge instead of the fancy technologies
SCOPES-DF (US) [30]	Project of Fab Foundation [31] develops pathways and resources to foster DF in STEM education	Teachers, principals, fabbers, makers, (students)	12-month experiential leadership programme, community of practice, global portal of DF lesson plans	New models and methods for teaching Curriculum development Lesson plans	Inquiry-based learning	Constructivism	
Teach-Thought (US) [32]	An idea and brand dedicated to innovation in education: their mission is innovation of education through the growth of innovative teachers	K-12 teachers principals district leaders, companies	1. 1-, 2- and 3-day workshops 2. Online virtual coaching	New skills and mindset of a maker educator: roles, reflection, self-assessment in making DT process to foster creativity Problem-solving Transformation of a school	Hands-on Highly interactive Educator-centred Personalise through the lens of inquiry		
Worlds of Making (US) [33, 34]	STEM-focused instructional technology training and PD, aims to provide professional learning experiences to empower and equip educators with maker-education skills	K-12 educators principals	1. Keynotes 2. Instructional coaching 3. 1-hour in-district online PD sessions; a series of four 4. 3- to 5-day workshops	Maker movement, strategies, and practices for establishing and facilitating a makerspace DT process	Hands-on Self-paced Research and evidence-based best practices	Maker movement	Every child has the right to invent, tinker, create, innovate, make and do
TECHNOLOGY-ORIENTED							
Fab Academy (US/Global) [6,35,36]	Internationally distributed campus of Fab Foundation [31] whose PD teaches principles and applications of DF (machines and processes) developed to teach hands-on skills	Open to potential individuals coming from technical and non-technical backgrounds	Distributed educational model of 5-month part-time student commitment: broadcasted lectures, interactive classes, online mentoring, lab days including hands-on experience with peers and mentors	The Fab Academy Diploma is comprised of 20 DF based certificates	Multi-disciplinary Interest-driven Combining lectures, hands-on, collaboration and sharing	Constructionism	Learn how to make (almost) anything

Most of the initiatives can also be specified by the focal points that are either the results of their contribution in the field or at the core of their philosophy and doing. Thus, LTML [23] applies the 'Focus, Fiddle, and Friends' approach, where they put *Focus* on providing information about makerspaces and computational thinking, apply *Fiddle* by playful time for curious tinkering and making, and value *Friends* in providing opportunities for reflection and sharing with peers. In addition to playing and sharing, they see their success in training educators to focus on teaching and learning strategies. They focus on practising and modelling what you preach, giving up the traditional expert role of teachers, thus offering the learning and contributing possibility to all community members. Finally, by exposing the technologies, but avoiding confusing participants by their 'glitz', they point out that the power shall be found in pedagogy, learning, and teaching rather than in the technology and tools. Likewise, *Maker Ed* [25] values the community and its people rather than tools and 'stuff'. Their fundament on maker education rests on mindset, meaning, and communities.

To investigate how development of professional practice can be conducted to empower and support educators in applying DF and DT activities in schools, this study takes as its point of departure an examination of PD within a real-world practice in the FabLab@SCHOOLdk organisation. Results and recommendations from research in PD in DF and DT and from research in PD in general (2.1) will be used to investigate different PD approaches and formats utilised in the organisation, and how such approaches and formats meet the challenges and needs of the stakeholders involved. Familiarity with other educational initiatives in the field of DF and DT (2.2) will serve both as a lens for investigation and discussion of the FabLab@SCHOOLdk's PD programmes and as inspiration for further development considerations.

3 RESEARCH METHODS AND CASE DESCRIPTION

To examine the research questions, a case study was conducted using ethnographic methods. A case study can be defined as "an empirical inquiry that investigates a contemporary phenomenon (the 'case') in depth and within its real-world context" [37, p. 16].The case study method was chosen because it was expected to catch the particularity and the complexity of the unique case and provide us with an understanding of its organisation, stakeholders, and activities under a variety of circumstances [38, 39].

In ethnographic research, researchers immerse themselves into the cultural scene studied, where they observe and interact with participants for a certain period to understand and record detailed aspects of the phenomenon [40]. The outcome of the research is expected to represent and reflect the phenomena in depth from the view of the participants being investigated. Ethnographic research was conducted during the enrolment in the FabLab@SCHOOLdk organisation. The field studies lasted five months. By physical presence, participative observations, and engagement in different stakeholder communities, the objective was to learn from the experiences of the partners and reach an in-depth understanding of how the initiative operates. Finally, the study draws on a variety of data collection methods as illustrated in figure 2.

3.1 FabLab@SCHOOLdk in a Research Context

FabLab@SCHOOLdk is a partnership and network that provides research-based, innovative education to primary and secondary school students as well as teacher education and a network where teachers, pedagogues, and principals find inspiration for working with DF, DT and 21st century skills. The initiative aims to develop new teaching concepts for project-based, student-centred hands-on learning in sync with the FabLearn Principles [22] and establish FabLabs as hybrid learning environments [8, 12].

Inspired by the work of the global FabLearn network and Aarhus University (AU), FabLab@SCHOOLdk offers DF and DT learning activities that give children opportunities to develop their understanding of technologies through examining, testing, and designing technological objects in a DF laboratory. Each of the three partnership municipalities has its own central FabLab.

The activities and the real working environment with its high-tech machines provide new ways of inspiring, familiarising, and equipping students with some of the skills and competencies considered as crucial in the 21st century, such as critical thinking, communication and collaboration, digital citizenship, design, innovation, mastering technologies, and complex problem solving. FabLab@SCHOOLdk [41] is built upon the FabLearn concept (see Table 1) [22], but adds a participatory design approach to the original STEM-oriented focus on constructivism and maker technology in education [42] by including DT in the development of the practice field [43].

A Design Process Model (Figure 1) developed at AU in collaboration with FabLab@SCHOOLdk [9] applies DT in order to help teachers and students to structure, navigate, and scaffold explorative design processes and projects from *research* to *creation* and *staging*. The structured process model includes six main steps: 1) Design Brief, 2) Field Studies, 3) Ideation, 4) Fabrication, 5) Argumentation, and 6) Reflection, which all include a set of concrete sub-activities [4].

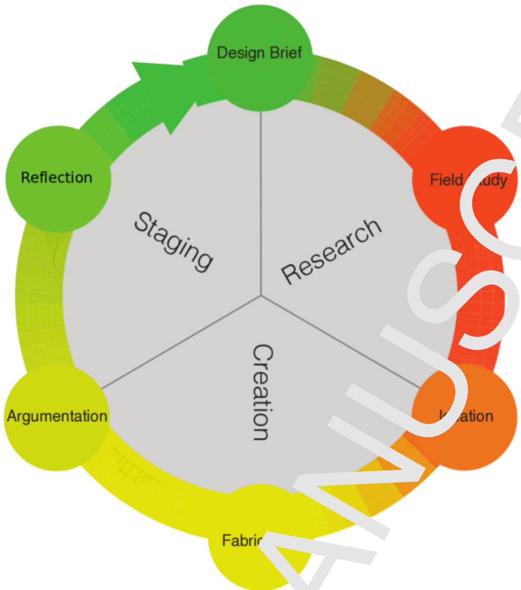

Figure 1. FabLab@SCHOOLdk Design Process Model.

3.2 Agents of FabLab@SCHOOLdk as Participants in the Study

FabLab@SCHOOLdk focuses on empowering educators through the FabLab Pioneer education. *A FabLab Pioneer* is a pedagogically, didactically competent person who is motivated to test new digital opportunities and able to combine this with an innovative angle on the subjects in primary and lower secondary school [44]. Basically, the Pioneers are expected to transform their thoughts into reality and be creative in problem-based teaching with DF and DT passing the same skills and competencies on to students.

The participants in the study, who acts as agents in the FabLab@SCHOOLdk, were identified during the ethnographic studies. In addition to the Pioneers, including teachers, pedagogues and teacher training college educators, we investigated the role of principals, FabLab leaders, project leaders, and the FabLab@SCHOOLdk organisation, including the national coordinator. We examined the work of FabLab leaders and FabLab learning supervisors (together the 'FabLab Team') in educating and supporting the Pioneers and the daily efforts of project leaders and the National Coordinator to develop the field of practice.

3.3 Data Collection Methods

The study generated informal interviews, photographs, and field notes from observations of the Pioneers and principals working in PD programmes and other events, including their considerations and reflections towards their learning processes, as well as from the daily practice of other FabLab@SCHOOLdk agents. The data collection is illustrated in the figure 2.

Participants/ Context	FabLab@SCHOOLdk/ National Coordinator	Project Leaders	FabLab Leaders	School Leaders	Pioneers [a]
FabLab Silkeborg	Documents	Participatory observations Informal interviews Field notes Photographs	Participatory observations Informal interviews Field notes Photographs	Participatory observations Field notes Photographs	Participatory observations Informal interviews Field notes Photographs
FabLab Spinderihallerne		Informal interviews Field notes Photographs	Informal interviews Field notes Photographs	Participatory observations Field notes Photographs	Participatory observations Informal interviews Field notes Photographs
FabLab Kolding		Informal interviews Field notes Photographs	Participatory observations Informal interviews Field notes Photographs	Informal interviews	Participatory observations Informal interviews Field notes Photographs
Network	Participatory observations Informal interviews Field notes Photographs Documents	Participatory observations Field notes Photographs Survey	Participatory observations Field notes Photographs Survey	Participatory observations Field notes Photographs Survey	Participatory observations Field notes Photographs Survey

[a] including teachers and teacher training college educators

Figure 2. Data collection from investigating the FabLab@SCHOOLdk organisation.

To gain deeper insight into relevant stakeholders' experiences with and perspectives on the FabLab@SCHOOLdk PD programmes and to examine to what extent current practices prepare teachers for the implementation of DF and DT activities in schools, we conducted two questionnaire surveys: one among teachers and teacher training college educators (N=17, referred to collectively as 'Pioneers') and another among principals, FabLab leaders, and FabLab project leaders (N=16, referred to collectively as 'Leaders'). Informants from each of the three partnership municipalities, 33 in total, were selected to obtain a group of all actors of importance for developing DF and DT activities in schools. The response rate was 76% for Pioneers and 63% for Leaders, which leaves us with a total of 23 answers from 70% of those surveyed. In addition to the stakeholders' experiences and perspectives, we asked about their opinion regarding possibilities and impediments as well as their suggestions as to how to increase the possibilities for conducting DF and DT activities in schools. An example of one of the questions is presented in figure 3.

Compared to the situation before you completed the education, how has the education in your experience prepared you for the application of DF and DT activities in your teaching?

	It has not inspired me to implement DF and DT activities in my teaching	It has inspired me to learn more, but I am not able to conduct DF and DT activities in my teaching yet	It has enabled me to initiate experiments with DF and DT activities in my teaching	I have been prepared very well for implementation of DF and DT activities in my teaching
4-hour Spot Courses	▢	▢	▢	▢
Certification Courses	▢	▢	▢	▢
Master Course (Aarhus University)	▢	▢	▢	▢
2-hour Introduction Courses	▢	▢	▢	▢
One-Year [illegible] Programme	▢	▢	▢	▢
Other education	▢	▢	▢	▢

Figure 3. A sample of survey question addressing teachers' benefit from participating in different PD activities.

3.4 Data Analysis of Ethnographic Studies and Surveys

Descriptive data from ethnographic research is visited throughout the enrolment and is utilised repeatedly in analysis processes in order to form a framework of the stakeholders that operate in the three partnership municipalities of FabLab@SCHOOLdk and the PD activities they provide. Results from the questionnaires are compared with rich data from ethnographic studies (see Figure 2). Patterns are mapped regarding statements from respectively project leaders, FabLab leaders, principals, Pioneers with a Master Course education (provided by AU) [9], Pioneers with long-term education and Pioneers with shorter education, showing:

- How they have acquired knowledge and competencies regarding DF and DT
- What they need themselves to conduct/support DF and DT activities
- What they in general consider as necessary/important to conduct/support DF and DT activities
- What they, from their position, can do to conduct/support DF and DT activities
- Which impediments they have recognised when trying to conduct/support DF and DT activities
- What they request Pioneers/Leaders, FabLab@SCHOOLdk organisation/the Danish educational system to do
- Their experienced satisfaction with and benefit of participation in the PD activities

Overall, our data analysis procedure followed the qualitative data analysis structure adapted from Ritchie and Spencer [45] including 1) reading and re-reading data, 2) revisiting the field and informants for additional data, 3) designing a data-based coding framework, 4) coding and mapping relations, and 5) interpretation and argumentation.

4 RESULTS

First, we examined how FabLab@SCHOOLdk in the three partnership municipalities trained educators through different PD programmes. Second, we investigated how FabLab@SCHOOLdk prepared educators for the application of learning activities involving DF and DT, and what still seems to be missing. Third, we recognised the work of the FabLab@SCHOOLdk organisation and its efforts to contribute to developing the field of practice. Fourth, we explored the impediments of the FabLab@SCHOOLdk stakeholders in implementing DF and DT in schools.

4.1 How does FabLab@SCHOOLdk Train Educators to Apply DF and DT in Education?

From the information we gathered through participatory observations, informal interviews, and document analysis, we formed a detailed account of the PD programmes that the FabLab@SCHOOLdk provides, as presented in table 2. Currently, the central FabLabs in the three municipalities provide a FabLab Pioneer Education initiated and developed in collaboration with FabLab@SCHOOLdk. Each has its own way of conducting PD programmes. In general, the Pioneers work and learn in small groups supported by larger local communities consisting of structured networks, where they share experiences, challenges, successes, ideas and inspiration with colleagues. Additionally, the study programme includes a yearly study trip and an annual learning conference as well as participation in other relevant events and courses. Also, courses addressed to principals, administrative staff, librarians and other professions are conducted in order to increase the understanding, develop a shared language, and spread and consolidate the initiative widely in the municipalities.

Table 2. FabLab@SCHOOLdk's setting for PD in DF and DT

Initiative (country)	Purpose	Target Group	Programmes	Content	Method	Approach	Focal Points
FabLab@ SCHOOL dk (DK) [41,44]	Partnership and a network, which empower teachers to implement DF, DT and 21st century skills in innovative education and support schools in developing new teaching concepts for project-based, student-centred, hands-on learning	K-9 teachers, pedagogues, teacher education teachers, principals	1. Introduction courses 2. Spot Courses 3. Certification Courses 4. Strategy Workshops 5. One-Year Pioneer Programme 6. Network activities: meetings, school visits, yearly study trip, annual conference	Mindset building, DF tools and materials, DT Real-world problem solving 21st century skills Computational thinking Pedagogy and new learning approaches Strategies for implementing FabLabs in education Leadership	Combining design theory, in-school-practice and peer-to-peer learning	Design-based learning Action learning Reflective practice	Five stakeholders identified as important fellow players: (1) Pioneers in developing teaching practice (2) Principals in developing strategies for supporting teachers (3) FabLab leaders in developing expertise within technology and pedagogy (4) Project leaders in developing meaningfulness in the educational organisation (5) FabLab@SCHOOLdk organisation supporting and facilitating internal and external collaboration

The PD activities are framed by the Design Process Model (Figure 1) and used intensively in all the Pioneers' PD programmes. The model is applied to provide a structure for the Pioneers' learning processes and for managing their problem-solving processes in the education. Further, the Pioneers are utilising the model in designing and implementing interventions in their own teaching practice. Also, with varying levels the PD activities are based on reflective practices.

4.1.1 PD through One-Year Pioneer Programme

The Pioneer programme at FabLab Silkeborg is a comprehensive PD programme conducted as an apprenticeship course with one full-day session per week for one year. The programme is based on the principles of *Action Learning* [46] and *Reflective Practice* [47]. It enables the Pioneers to understand technology by examining, testing, and designing technological artefacts, and reflecting on their learning and further development of learning processes in interaction with FabLab learning experts.

In the beginning, the focus is both on developing the Pioneers' technological competencies and on mindset building. New Pioneers are for example given an assignment to assemble their own 3D printers (see Figure 4). The process aims at building ownership of the technology, willingness and knowledge how to use or fix the machine if needed, but also at preparing the Pioneers for getting into the right mindset to manage technology by themselves (instead of immediately calling for ICT-service in connection with technical problems). Additionally, the Pioneers are introduced to different technologies, and they are provided with an understanding of the construction of the technology and its potentials in an educational context. Thereafter, technology-based knowledge and problem-solving experiences are built into concrete, hands-on projects, including interventions in the pioneers own teaching practice. The FabLab Team provides them with feedback that forms the basis for reflective practices.

The Pioneers work on a goal-oriented basis towards creating a transfer of learning. Thus, what is learned in the central FabLab is expected to be rooted in their teaching practice in schools. They are provided with shared contents as well as individualised learning paths based on their background and previous skills in DF and DT, their professional and motivational interests, and their ways of learning. The P programme is based on a belief that learning is embedded in a social context where participants in the Lab learn from and with each other. Consequently, different networks are established for both new and old Pioneers. These networks act as a forum for inspiration, experiments, reflection, sharing and discussion of technological and didactical challenges experienced in the Pioneers' teaching practice. The networks are facilitated by the FabLab Team.

Figure 4. The Pioneer PD programme. Educators build their own 3D printers at FabLab Silkeborg.

4.1.2 Competence Development through Courses and Network

FabLab Spinderihallerne in Vejle is passionate about teaching how the new technologies can be used. They are willing to work across disciplines and to pursue individual interests. The FabLab leaders help schools apply digital technologies and build their own FabLabs. They are providing a framework of courses open to Pioneers, principals, and consultants:

1) *Practical and didactically oriented four-hour Spot Courses* intended for those who have no experience with DF and DT activities and digital technologies,

2) *Machine certification courses* aimed at enabling the participants to use certain digital machines independently, including 3D printer, laser cutter, and CNC milling machine

3) *A series of workshops for schools and administrative staff*, introducing FabLab principles, benefits, and requirements when establishing local FabLabs.

4.1.3 Inspiration through Introduction Courses

FabLab Kolding is a newcomer to the organisation. Their PD programme aims to introduce and familiarise the Pioneers with DF and DT technologies and inspire them to initiate similar learning activities in schools. Since only a few schools have invested in DF technologies, the FabLab focuses on introducing DT and various digital technologies.

The programme consists of six two-hour meetings, where the Pioneers get an overview and understanding of the field, design processes, and digital technologies. Furthermore, the FabLab Team is offering a series of activities for classes. They are planned by the team or collaboratively with educators from local schools and support subject-based or cross-curricular contents.

4.2 To What Extent does FabLab@SCHOOLdk's PD Programmes Prepare Educators to Apply DF and DT in Schools?

The findings reveal that an inquiry-driven and project-based learning approach supported even inexperienced educators in becoming familiar with problem-solving processes using technologies as something meaningful, they can master and enjoy. One Pioneer stated as follows: "*It has inspired me to include it (DF and DT activities] much more in the way I am considering my teaching.*" The education has enabled them to invite colleagues and students to experiment with technologies related to different curricular activities. One Pioneer described it as follows: "*It has provided my voice with much more authority, when I am telling about what I am doing with the students*".

The surveys revealed that a Master Course (AU) [9] and the One-Year Programme provided educators with opportunities to develop both the mindset and skills to use DF and DT activities in their teaching practice. Mixed results were identified regarding Spot Courses and Certification Courses as the Pioneers either reported that the courses had inspired them, but not enabled them to conduct FabLab teaching, or that they had prepared them very well. Two-hour introduction courses provided the educators with a very narrow insight into the field. Nevertheless, they seemed to enable some Pioneers to conduct incipient DF and DT activities, where they were copying or repeating the activities using a more instructional approach. As an example, they had learned to use a 3D modelling programme, but were not able to transfer files from computer to a 3D printer or manage the 3D printer. Consequently, it was identified how the Pioneers at these Intro Courses were dependent on the support from the FabLab Team for refinement of files and printing the product. The realisation of suggested contents and practices for educators' PD in DF and DT [9, 11] towards learning activities provided in the FabLab@SCHOOLdk PD programmes is illustrated in figure 5.

Understanding of complex design processes was supported by widespread use of the Design Process Model (Figure 1). Spot Courses were framed by this model, and they were based on well-developed plans. On Strategy Courses, the participants worked with relevant challenges from their local school practice and used the model as a tool in their problem-solving processes. The One-Year Programme applied the model as a didactic framework for their activities, where the Pioneers learned about DT processes, designed DF and DT lesson activities, and discussed pedagogical and didactic benefits and challenges related to this new teaching approach. Similar activities were implemented on the Master Course, where the Pioneers were also introduced to theoretical knowledge on the subject. In the Network Activities, the Pioneers developed, presented and shared concrete learning activities, and discussed potentials and challenges.

Educational Programme / Content/ Learning Activity	2-hour Introduction Courses	4-hour Spot Courses	4-hour Certification Courses	4-hour Strategy Courses	One-Year Pioneer programme	Master Course (AU)	Network Activities
Understanding of complex design processes [a]		X		X	X	X	X
Managing digital technologies and design materials [a]	X	X	X		X		X
Balancing different modes of teaching [a]					X	X	X
Introducing design theory [b]		X		X	X	X	X
Incorporating in-school practice [b]		X			X	X	X
Supporting peer-to-peer learning [b]				X	(x)	X	X

a Smith, Iversen & Veerasawmy [11]
b Hjorth, Smith, Loi, Iversen, & Christensen [9]

Figure 5. The realisation of suggested contents and practices for educators' PD in DF and DT [9, 11] in the PD programmes provided by FabLab@SCHOOLdk.

Managing digital technologies and design materials was supported at Intro Courses, Spot Courses, Certification Courses and the One-Year Programme. Naturally, the different amount of time available left the Pioneers with different possibilities for developing and sustaining sufficient skills. As Strategy Courses and the Master Course operated on a more theoretical level, the Pioneers were expected to obtain hands-on experiences in other contexts.

Balancing different modes of teaching was supported by the One-Year Programme, the Master Course and Network Activities, where the Pioneers were inspired to shift from a more traditional, teacher-centred expertise role and learn why and how to act as a facilitator in classroom activities and involve the students in reflective dialogues. These PD activities are time-consuming and not identified on Intro Courses, Spot Courses, Certification Courses, or Strategy Courses.

Introducing design theory was to some extent identified on Spot Courses, Strategy Courses, in the One-Year Programme and Network activities, where the Pioneers were using the Design Process Model in activities as mentioned above. However, literature and lectures in DT and DF were only described in the Master Course.

Incorporating in-school practice was identified in relation to Spot Courses, the One-Year Programme, the Master Course and Network Activities, where Pioneers developed educational DF and DT activities and attempted to introduce them in their teaching in local schools. The level of lesson plans developed and shared from these activities was different. They varied from mainly brief inspiration in online network groups, to more thoroughly prepared teacher instructions and very detailed pedagogical and didactic reflections.

Supporting peer-to-peer learning was primarily identified on Strategy Courses, the Master Course and in Network Activities, where the Pioneers were expected to collaborate and co-create. At the One-Year Programme, technology skills were primarily developed individually with the support of the FabLab Team, while lesson plans were developed and passed on to colleagues collaboratively. The learning design in the other PD programmes was more individualised and collaboration seemed to happen coincidently. However, Network Activities inspired the Pioneers' interest and engagement in further experiments and provided them with some of the same activities as the One-Year Programme. It may be fair to emphasise that the Network Activities were conducted by the FabLab Team and strongly related to the PD programmes aiming at supporting implementation of DF and DT activities in schools.

The PD programmes were practical rather than theoretical. From the Pioneers' point of view, readings were considered as an additional activity, and thus the level and the amount of theory varied significantly. It seemed difficult to implement theory-based lectures and peer-to-peer reflection in the current PD programme. 'Introducing Design Theory' is noted in relation to Spot Courses and the One-Year Programme but refers mainly to the use of the Design Process Model (Figure 1) for scaffolding activities in the FabLab and at schools. Some of the Pioneers call for didactics and theory. *"Project-based and process-oriented teaching with relevant professional feedback and possibilities to contact the Knowledge Centre for support or collaboration"* was mentioned by one Pioneer as crucial for conducting DF and DT activities. Some teachers expressed that they were or would become more competent once they had completed both the theory-oriented Master Course and technology-oriented, practical Spot Courses or the One-Year Programme.

When familiarising themselves with the technologies available in the FabLab environment, the Pioneers learned about hardware, firmware, and software. In addition, they gradually adopted a new mindset and more active roles when it came to making decisions and applying, using, and even fixing technologies. Their abilities to manage digital technologies seemed to be in line with the length of the educational activities. During the two-hour introduction courses, the Pioneers were mainly working with software, e.g. for 3D modelling or coding, and during the four-hour Spot and Certification Courses they were learning to use both hardware and software for DF, while the more intensive One-Year Programme demanded the Pioneers to understand the machinery and work with firmware as well.

The Pioneers found the DF and DT activities valuable and relevant. They were to a great extent adopting the mindset of doing things by themselves. Some of them missed concrete ideas for applying the knowledge and skills in their teaching practice. Consequently, a big part of the Network Activities consisted of collaborative development processes of ideas or specific courses based on a topic (e.g. Christmas), subject (e.g. coding in math), cross-curricular theme (e.g. plastic waste in the ocean), or technologies (e.g. games with micro:bits). The investigation showed that DF and DT activities had been applied in various subjects to help meet the current goals of curriculum (see Figure 6 or visit www.fablabatschool.dk for concrete examples). Still, the Pioneers needed time both for immersion and for implementing the skills and competencies they had acquired during the Pioneer programme into the curricular activities at the school, including preparation time together with colleagues.

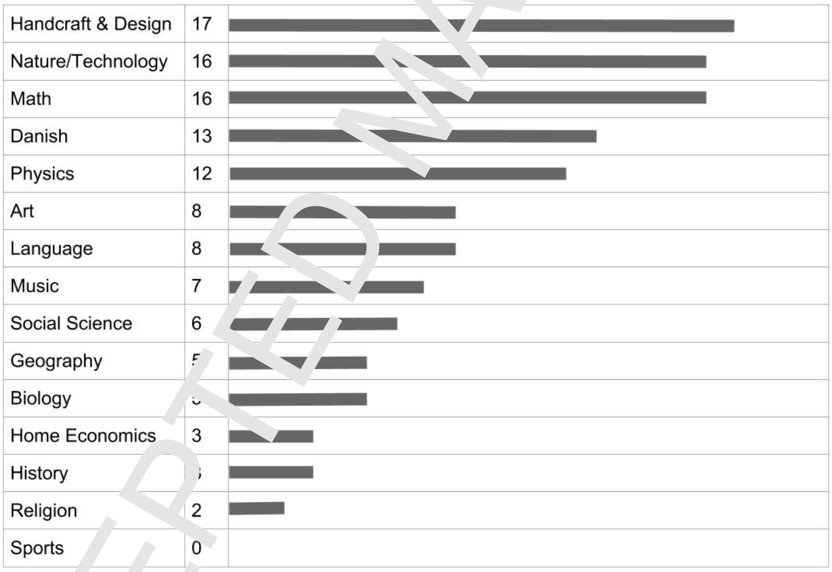

Figure 6. Subjects involved in DF and DT activities in the organisations surveyed.

4.3 How does FabLab@SCHOOLdk Develop a Field of Practice in DF and DT in Education?

The administrative level of FabLab@SCHOOLdk in the three municipalities is quite consistent. The leaders of the school departments in the three municipalities function as heads of the organisation. They define the overall funding and collaborate with the local, central FabLabs. Every municipality has its own FabLab project leader who coordinates the activities at an administrative level and is responsible for finances and partnerships. Their focus is on developing central FabLabs and FabLab networks in the organisation to act as knowledge centres. The national coordinator acts as head of the administrative level among the school department leaders and the project leaders, connecting the three municipalities, servicing both the school department leaders and the project leaders, and coordinating and facilitating activities.

The local FabLab Teams include a FabLab leader who is responsible for running the lab. In addition to task-solving inside and around the lab, the focus area of the FabLab leader is the Pioneer education, teaching, and networking. The FabLab Team also includes FabLab learning supervisors, whose daily work is in and around the lab focusing on teaching and supervising the Pioneers in DF and DT activities, pedagogically and technically. The organisational structure of the FabLab@SCHOOLdk in 2017-2018 is illustrated in figure 7.

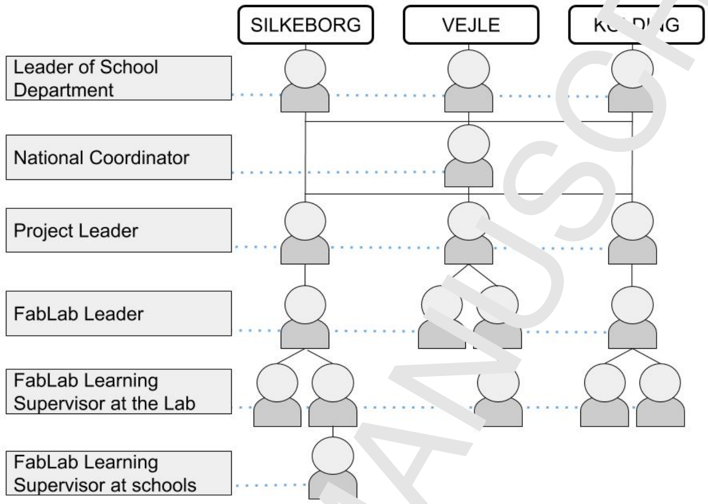

Figure 7. The organisational structure of the FabLab@SCHOOLdk.

Across varying data, the study identified five important stakeholders who support and develop a field of practice:

(1) Pioneers - key actors in developing new teaching practices
(2) Principals - enabling and supporting teachers in adopting new methods and competencies and initiating new learning activities in schools
(3) FabLab leaders - providing the Pioneers with PD within technology and pedagogy
(4) Project leaders - supporting the work of FabLab leaders and making it meaningful in and around the educational organisations
(5) The FabLab@SCHOOLdk organisation - facilitating and developing internal and external collaboration

These five groups of stakeholders interact and establish an organism, where everyone holds a crucial role in developing the practices further. The roles and tasks - what each of the stakeholders provides for the organism - are summed up and illustrated in Figure 8. Vice versa, the figure illustrates what the stakeholders ask from each other to be able to fulfil and develop their own role in the organisation.

4.3.1 Developing Collaboration

The value of continuity, collaboration, and community was visible throughout the data. One of the overall tasks of FabLab@SCHOOLdk is *developing collaboration*. Together with National Coordinator, project leaders develop the organisation and field of practice collaboratively. The Pioneers saw the value of the organisation in a continuation of the teacher education, but also in developing common frameworks and strengthening the collaboration possibilities between the partnership municipalities.

The Pioneers suggested that FabLab@SCHOOLdk should create an idea bank for inspiration and sharing. The Pioneers who had completed both the Master Course and other programmes providing them with technological competencies did not express a similar need for concrete materials. These more experienced Pioneers used the network for inspiration and knowledge sharing, where they displayed their activities in the Facebook group for Pioneers and appreciated the opportunities to get new inspiration on the yearly study trip. They also communicated via the FabLearnDK conference [48] or cross-municipal network activities. This collaboration seemed to be supported by principals who suggested that the organisation continues spreading the knowledge among schools.

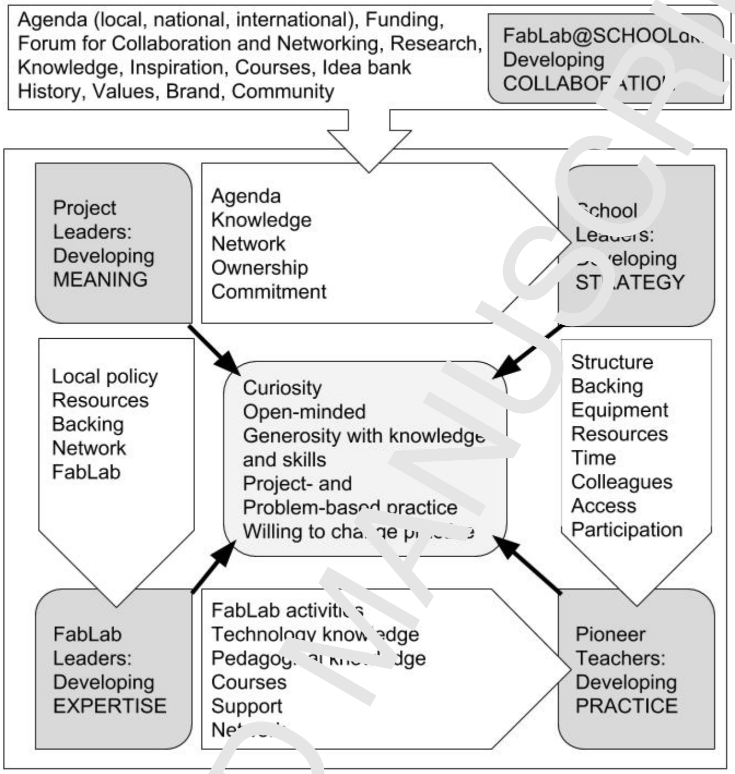

Figure 8. The framework of five important stakeholders in the FabLab@SCHOOLdk organisation.

4.3.2 Making the Concept Meaningful and Developing Expertise

Project leaders *make things meaningful* in and around the organisation. They are key actors and important stakeholders when it comes to spreading knowledge, creating connections, and supporting the formation of communities. The role of project leaders is twofold: they prime principals by setting the agenda, providing them with knowledge and networks, and helping them to develop a commitment to and ownership of the DF and DT activities at their local schools. They are also responsible for establishing a framework for the central FabLab and support the work of FabLab leaders, providing resources, backing, and publicity.

FabLab leaders provide and *develop expertise* within technology and pedagogy. An important vision for learning in the FabLab is to avoid providing too much basic level instruction. Instead, FabLab leaders strive to facilitate individual learning processes and observe at which level the learners can guide their own learning in directions that best serve their interest and skills. FabLab leaders are mindful not to intervene at too early a stage, but instead let learners develop self-efficacy [49] to handle failure and errors, to rethink and try again, to manage frustration, and to build their own emotional drivers to hook onto the projects. FabLab leaders considered this approach necessary to develop 21st century skills such as searching for relevant information, discussing, knowledge sharing, and collaborating. The role of the FabLab Team is to find a balance between providing a safe environment, where learners dare to make mistakes, and at the same time challenging them to cross the line and move into the zone of learning.

4.3.3 Developing Strategy and Teaching Practice for Schools

Principals hold a significant position in *developing strategies* for schools. They enable and support teachers in adopting new methods and competencies and initiating new learning activities in schools. The Pioneers appreciated and considered the support from principals crucial for initiating DF and DT activities at the schools. They asked for their principals to lay down a clear framework and set aside a number of working hours for preparing and implementing the activities. They would also like their principals to support their work and help them demonstrate the importance of DF and DT activities to school community.

When principals are informed, involved, and provided with adequate knowledge by researchers and project leaders, they were willing to support FabLab education and development processes at the schools. At FabLab Silkeborg, the processes and the value of education are reflected throughout the year. There, the PD programme starts with an conversation about expectations between a Pioneer, a principal, and a FabLab Team member where a personal learning path is planned based on the competencies needed at the school and the Pioneer's learning focus. Later, a reflective mid-term discussion is held to facilitate a high extent of awareness, objectives, goal management, and meaningfulness across the stakeholders.

The Pioneers contribute to *developing teaching practice*. They are dependent on the support from FabLab leaders and the FabLab Network and on the principals' strategy for carrying out DF and DT activities in the local schools. FabLab leaders, project leaders, and principals considered curiosity, courage, and openness as the most essential qualities for developing FabLab skills, activities, and practices. Likewise, willingness to share knowledge with others and be open to adopting new knowledge, a new mindset and new perspectives were considered important. The Pioneers are not required to throw away their old teaching habits but encouraged to rethink and challenge their traditional authority and expertise and adopt an exploring role. Focus may not be on 'me', but on 'we'. How can we do this together – make the students work collaboratively to achieve a shared future goal?

4.4 What Prevents Stakeholders in FabLab@SCHOOLdk from Implementing DF and DT in Schools?

The study reiterated considerable impediments that the Pioneers and principals are confronted with in their daily practice, thus impacting their possibilities to implement DF and DT activities in schools. Some of the key elements in initiating the activities seemed to be sharing, collaboration, resources, and time, not just during the education, but also afterwards at the schools. Both the Pioneers and principals needed to allocate time for these activities, since such development processes do not happen during a few hours' vacuum, but in immersion and in interaction with others. Consequently, the Pioneers experienced their role as too individualised and lonely. The explorative approach and the mindset of doing things by yourself applied in the One Year Programme were among the first and most discussed matters during the education. The Pioneers expressed how their attempts to apply these approaches in classroom contexts challenged their traditional role and authority significantly and required them to rethink their expert role and instead become a co-learner on par with their students and move from teaching to facilitating learning.

To cope with the challenges, firstly, the Pioneers wanted more professional mentoring. Secondly, they desired to work in a project team to develop activities together and would like their colleagues to be engaged in the DF and DT activities. They were willing to share their knowledge and do what they are educated to do, thus not just benefiting their own teaching practices, but also spreading and disseminating their skills at the schools: "*I would like to have more colleagues on the wagon, but it can be difficult in a busy working day to find the time to persuade them*". They seemed to have adopted this role from the FabLab programme and network, but some feel that their colleagues were uninterested. Therefore, they urged their leaders to openly demonstrate support. Furthermore, even though the Pioneers were eager to hold face-to-face meetings, not all municipalities had managed to provide them with sufficient resources to participate regularly.

As in many other settings, in addition to lack of time, lack of money, DF machines and other resources to implement the visions were mentioned as important barriers for conducting DF and DT activities at schools. Some Pioneers were annoyed that even though they had the education and willingness to implement the activities, external savings and regulations prevented them from realising activities. Principals asked for resources and complained they could not afford activities due to lack of finances. They regretted having to be faced with a priority challenge among other competitive agendas.

Finally, the narrow frames and structural challenges of schools were criticised both by the principals and the Pioneers. The Pioneers, principals, FabLab leaders, and project leaders in this study all pointed to the fact that the current curricular structure in Denmark does not support initiation and development of DF and DT activities. The limitations of the curriculum with its many specific goals were seen as the main obstacle to realising activities in school practice. Hence, the stakeholders called for national definitions of the field as well as for central strategies and curricular goals.

5 DISCUSSION

The constructionist/constructivist approach to learning is recognised across several investigated initiatives as a beneficial basis for developing competencies in the field of DF and DT (as illustrated in Table 1 and 2). Learning through experiments, creation of constructions which act as objects for collaborative discussions, and reflection are promoted to provide participants with not just the requested technological competencies, but also with skills for collaboration, creativity, problem-solving, and critical reflection. An inquiry-driven and project-based learning method allows learners to explore the functionality of technologies and learn how to analyse, manage, modify, and construct either artefacts created by technologies or the technologies themselves.

5.1 Preparing Educators

Peer-to-peer learning and explicit collaborative written, or oral reflection seem to be activities from the three-way structured framework [9], which are not fully utilised in the FabLab@SCHOOLdk PD programmes. Using these learning activities consistently and systematically might be a way to increase the participants' opportunities to externalise their thoughts and develop meaningfulness together. Framing collaboration and shared reflection may enhance the Pioneers' opportunities to learn from each other's experiences, successes, failures, and perspectives.

Likewise, it seemed difficult to implement theory-based lectures and consistent peer-to-peer reflection in the current PD programmes. The courses did not include any common theoretical material and reading was regarded as optional. Some of the Pioneers requested educational initiatives with a combination of apprenticeship and specific courses in didactics and theory. It could be beneficial to introduce a common repertoire of reading material and build in time for collaborative reflection and connection between theory and practice, regarding both pedagogy and technology. Such activities may support development of a shared consciousness, language, and mindset towards DF and DT in education.

The investigated educational initiatives can be categorised according to the main content and perspective from which the education is designed. Fab Academy [35], the Certification Courses, and the Introduction Courses conducted by FabLab@SCHOOLdk are primarily designed from the perspective of technology. Their aim is to provide participants with specific technology skills. On the other hand, the Master Course, and the Spot Courses are structured according to the Design Process Model, while they and the One-Year Programme to a higher extend emphasised pedagogical aspects.

According to the survey respondents, the Master Course and the One-Year Programme prepared the Pioneers very well for the implementation of DF and DT activities in their teaching practise. They had developed sufficient technological competencies and collaborated with Pioneer colleagues with whom they both shared a network and a mindset. Among the investigated initiatives, mindset, people, and communities are considered as more important than 'the stuff' [25] or 'glitz' [23] of technologies: "*We know that people need support, tools, resources, and community to fully participate in the opportunities offered. We know that learning is contextual and social*' [25].

Inspired by the LTML [23] and their method for learning: The 'Focus, Fiddle and Friends approach' (see Table 1), it may be relevant to consider how to maintain an open and playful atmosphere if all learning activities are levelled at solving real-world problems, constructing specific products, or reaching specific goals. *Focus* on DF and DT could also be applied through *Fiddling* in a playful manner with curious tinkering and making, while reflecting and sharing with *Friends*.

5.2 Developing a Field of Practice

Development processes as described in this research confront disturbances and interferences from the surrounding society, local culture, and national legislation. Exploring FabLab@SCHOOLdk and some other initiatives in the field of DF and DT emphasised the importance of stakeholders becoming involved in realising the PD programmes. Table 1 shows how the initiatives are providing different programmes with diverse purposes for various stakeholders considered as central in the development processes: teachers, principals, maker education facilitators, directors of maker programmes, policy makers, and educational administrators. It seems relevant to acknowledge all stakeholders in the equation and provide support at all levels.

In the case of FabLab@SCHOOLdk (see Figure 8), when principals are supported by project leaders and invited to participate in education, strategic workshops, study trips, and conferences, they are developing a shared language with the Pioneers and leader colleagues, and they are building a shared understanding of necessities, constraints, and possibilities. Without this, it may be difficult to realise the common mission of applying DF and DT in the education. When project leaders, the national coordinator and the heads of school departments collaboratively define strategies and objectives for future steps, it is easier for schools, principals, Pioneers and FabLab leaders to navigate and support the desired development. The network relies on the project leaders' efforts to communicate, coordinate and undertake the daily leadership, and the activities in the municipalities would probably not reach the same level of activity, influence, and professionalism without the contribution and coordination of the FabLab@SCHOOLdk organisation.

Following their education, many Pioneers are very dedicated to continuing the development and spreading the initiatives in local schools and among their colleagues. Here, principals play an important role in allocating sufficient resources, but they are trapped between competitive agendas derived from influential gatekeepers. Figure 9 illustrates the identified gatekeepers, such as the Ministry of Education, with their curricular demands, and the local politicians with their limited budgets.

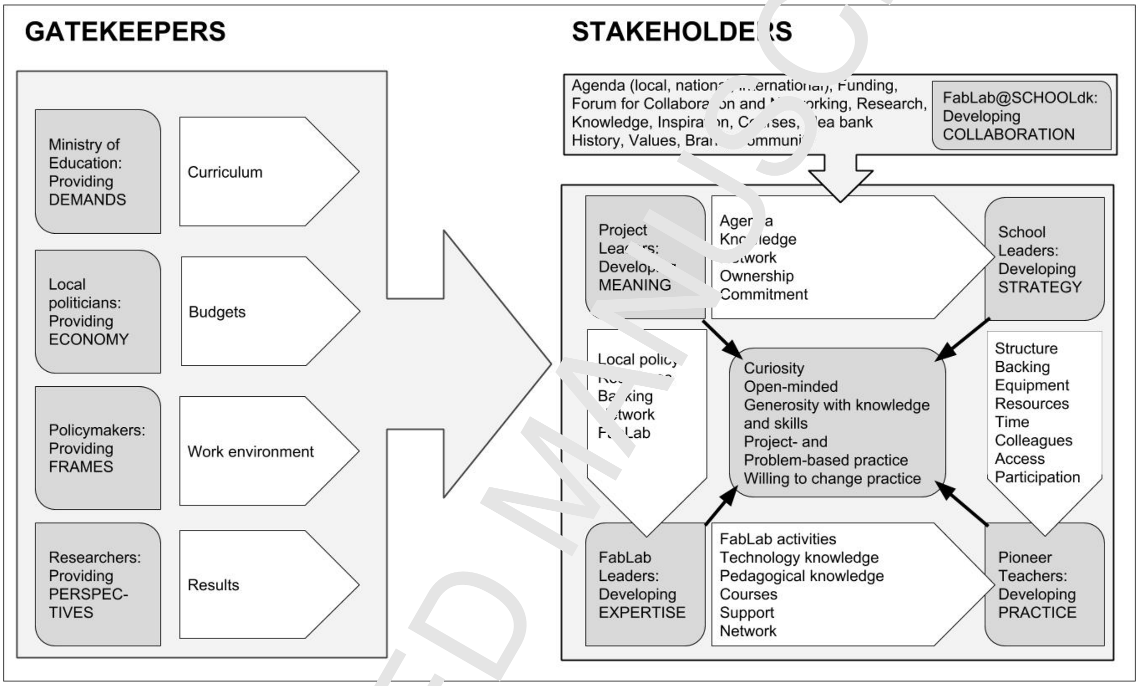

Figure 9. Stakeholders and gatekeepers of importance for the FabLab@SCHOOLdk organisation.

If the endeavour to implement DF and CT activities is to become a sustainable educational practice rather than a one-hit wonder, awareness of procurement of technologies, unconfident employees, national policy making, equal opportunities, and knowledge progression may be as relevant as fascination of fancy technologies, as suggested by Eriksson and colleagues [29].

FabLab@SCHOOLdk seeks to facilitate active, learner-driven education and development of a repertoire of experiences with technologies. This approach emphasises the importance of educational activities, where the FabLab Team does not provide Pioneers with 'the right answers'. Instead, they offer opportunities for individual and collaborative exploration, problem solving, dialogue, reflection and argumentation. These are time-consuming processes and consequently difficult to implement in the short two- or four-hour courses. Regardless of the length of the courses, there was a call for more hands-on practice, where the Pioneers could sustain and further develop their technology skills. However, there seems to be a similar call for team-based time to meet, create, craft, and refine lesson plans and reflect on pedagogy [21]. Thus, we suggest that future iterations of PD initiatives consider a 1:1:1 model (Figure 10), with equilibrium between time for '*inspiration at the courses*' and '*time for immersion in the field*' and *'development of professional practice'*.

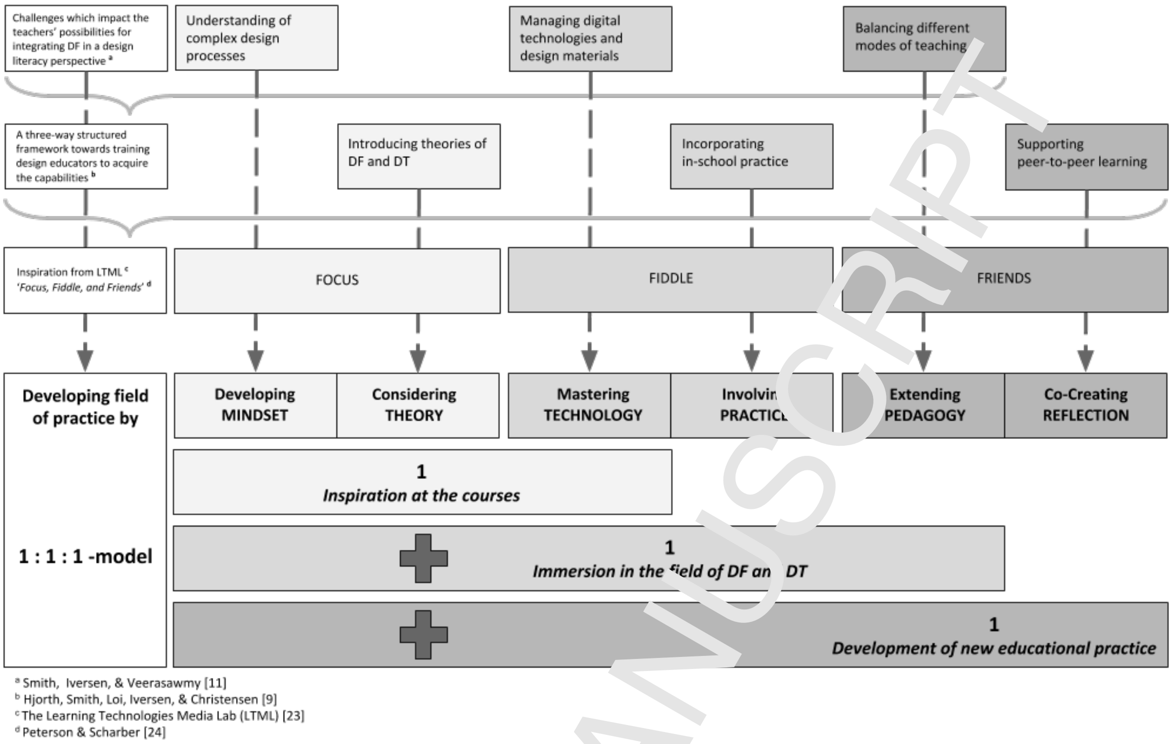

Figure 10. The 1:1:1 -model for PD activities in the field of DF and DT.

PD activities may provide INSPIRATION not only about technologies, but also FOCUS on initiating reflection on THEORY in order to DEVELOP CONSCIOUS MINDSET regarding DF and DT in education.

Time for being IMMERSED in the field of DF and DT and for FIDDLING with TECHNOLOGY seems to be necessary regardless the type of education for developing confidence to adopt DF and DT in teaching PRACTICE.

FRIENDS as colleagues from local network community, seem to enhance COLLABORATIVE REFLECTION and the possibilities for developing, spreading and sustaining a NEW EXPANDING PEDAGOGICAL PRACTICE in schools.

6 CONCLUSIONS

This study has investigated how development of professional practice can be conducted in order to empower and support educators in implementing DF and DT activities in schools. Because the study engaged itself both with the administrative and executive agencies and with the learners, it was possible to communicate different perspectives on the subject.

FabLab@SCHOOLdk has established an environment where research is converted to practice, providing education, and inviting participants to learn and contribute to the community. The findings illustrate how implementation of DF and DT activities in schools relies on more than just teachers' acquiring adequate skills. Five stakeholders are identified as important fellow players who seem to interact and establish an organism, where no one can be eliminated without disturbing or destroying the progress.

Finally, the study emphasises that implementation of DF is about much more than FabLabs and technologies. They are just the tools. It is primarily about schools and learners – their approach to DF and DT activities – and what happens at the schools once teachers have completed their education. For future research, it may be relevant to investigate to which extent the investment in FabLab@SCHOOLdk's PD programmes has had an impact on teaching practice at the local schools and the progress of the students.

REFERENCES

[1] P. Blikstein, Z. Kabayadondo, A. Martin, D. Fields, An Assessment Instrument of Technological Literacies in Makerspaces and FabLabs. *Journal of Engineering Education* 106 (2017) 149–175. http://doi.org/10.1002/jee.20156

[2] P. Blikstein, Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of Machines, Makers and Inventors* (pp. 203–222). Bielefeld: Transcript Publishers, 2013.

[3] M. Eisenberg, Output devices, computation, and the future of mathematical crafts. *International Journal of Computers for Mathematical Learning 7*, (2002) 1–44.

[4] Y. Kafai, D. Fields, & K. Searle, Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review*, 84(4), (2014) 532–556. https://doi.org/10.17763/haer.84.4.46m7372370214783

[]5 H. Schelhowe, Digital Realities, Physical Action and Deep Learning. FabLabs as educational environments? In *FabLab: Of Machines, Makers and Inventors*. 93–103. Transcript Verlag, Bielefeld, Germany. 2013.

[6] N. Gershenfeld, How to Make Almost Anything. *Foreign Affairs 91*(6), 2012, 43–57

[7] S. Lassiter, C. McEnnis, J. Morrison, H. King, B. Skarzynski, & A. B. Waldman, Training and Inspiring Educators in Digital Fabrication: A Professional Development Framework, *Proceedings from the Fab 9 Research Stream, (*2013). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.635.7938&rep=rep1&type=pdf (accessed 7 January 2019).

[8] R. C. Smith, O. S. Iversen, M. Hjorth, Design thinking for digital fabrication in education. *International Journal of Child-Computer Interaction* 5 (2015): 20–28. http://doi.org/10.1016/j.ijcci.2015.10.002

[9] M. Hjorth, R. C. Smith, D. Loi, O. S. Iversen, K. S. Christensen, Educating the Reflective Educator, *Proceedings of the 6th Annual Conference on Creativity and Fabrication in Education – FabLearn 16* (2016). http://doi.org/10.1145/3003397.3003401

[10] V. Barr, C. Stephenson, Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads,* 2(1) (2011) 48–54. doi:10.1145/1929887.1929905

[11] R. C. Smith, O. S. Iversen, R. Veerasawmy, Impediments to Digital Fabrication in Education. *International Journal of Digital Literacy and Digital Competence* 7 (2016): 33–49.

[12] M. Hjorth, K. S. Christensen, O. S. Iversen, R. C. Smith, *Digital Technology and design processes II: Follow-up report on FabLab@School survey among Danish youth*, 2017. http://doi.org/10.7146/aul.200.145

[13] A. Hira, C. H. Joslyn, M. M. Hynes, Classroom makerspaces: Identifying the opportunities and challenges, *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, (2014). doi:10.1109/fie.2014.7044263

[14] K. M. Oliver, Professional Development Considerations for Makerspace Leaders, Part One: Addressing 'What?' and 'Why?'. *TechTrends, 60*(2) (2016a), 160-166. doi:10.1007/s11528-016-0028-5

[15] K. M. Oliver, Professional Development Considerations for Makerspace Leaders, Part Two: Addressing 'How?'. *TechTrends, 60*(3) (2016b), 211-217. doi:10.1007/s11528-016-0050

[16] B. Trilling, C. Fadel, *21st century skills: Learning for life in our times*, San Francisco, Jossey-Bass, CA, 2009.

[17] P. Freire, *Pedagogy of the Oppressed*. New York: Continuum. 1970.

[18] S. Loucks-Horsley, K. E. Stiles, S. Mundry, N. Love, P. W. Hewson, *Designing Professional Development for Teachers of Science and Mathematics.* Thousand Oaks, CA: Corwin Press. 2009.

[19] T. Murphy-Latta, *A Comparative Study of Professional Development Utilizing the Missouri Commissioner's Award of Excellence and Indicators of Student Achievement*. Proquest: Umi Dissertation Publishing, 2011

[20] R. DuFour & R. Eaker, *Professional Learning Communities at Work: Best Practices for Enhancing Student Achievemen*t. Bloomington: National Educational Service. 1998.

[21] J. Stigler & J. Hiebert, *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York, NY: The Free Press. 1999. http://ist-iiep.iiep-unesco.org/cgi-bin/wwwi32.exe/[in=epidoc1.in]/?t2000=011347/(100).

[22] FabLearn. https://fablearn.org/, 2018 (accessed 22 October 2018)

[23] The Learning Technologies Media Lab (LTML). http://lt.umn.edu/about.html, 2018 (accessed 22 October 2018)

[24] L. Peterson, , C. Scharber, Learning About Makerspaces: Professional Development with K-12 Inservice Educators. *Journal of Digital Learning in Teacher Education, 34*(1) (2017), 43-52. doi:10.1080/21532974.2017.1387833

[25] Maker Ed. https://makered.org/professional-development/, 2018 (accessed 22 October 2018)

[26] Maker Promise. https://makerpromise.org/, 2018 (accessed 22 October 2018)

[27] Maker Promise Year Two raport. http://digitalpromise.org/wp-content/uploads/2018/06/Maker-Promise-Annual-Report-Year-Two.pdf (accessed 22 October 2018)

[28] Makerskola. http://makerskola.se/, 2018 (accessed 22 October 2018)

[29] E. Eriksson, C. Heath, P. Ljungstrand, P. Parnes, Makerspace in school — Considerations from a large-scale national testbed, *International Journal of Child-Computer Interaction, 16*, (2018) 9-15. doi: 10.1016/j.ijcci.2017.10.001

[30] SCOPES-DF. https://www.scopesdf.org/about-scopes-df-project, 2018 (accessed 22 October 2018)

[31] Fab Foundation. http://www.fabfoundation.org/ 2019 (accessed 12 January 2019)

[32] TeachThought. https://wegrowteachers.com/ 2019 (accessed 12 January 2019)

[33] Worlds of Making. https://www.worldsofmaking.com/professional-development, 2019 (accessed 12 January 2019)

[34] Worlds of Making. https://docs.google.com/document/d/1yBMXmNuEax8X_rFX4SJ5YYv2F50[illegible]wAzfm[illegible]y4HEH4E/edit, 2019 (accessed 12 January 2019)

[35] Fab Academy. http://fabacademy.org/, 2018 (accessed 22 October 2018)

[36] S. Lassiter, Fablabs: Thoughts and Remembrances, in: J. Walter-Herrmann, C. Büching (Eds.) *FabLab: Of machines, makers and inventors*, Transcript, Bielefeld, 2013, pp. 249–257.

[37] R. K. Yin, *Case Study Research Design and Methods (5th ed.)*. Thousand Oaks, CA: Sage. 2014.

[38] C. Robson, *Real World Research*. Oxford: Blackwell. 2002.

[39] R. Stake, *The Art of Case Study Research*. Thousand Oaks, CA: Sage. 1995.

[40] J. P. Goetz, & M. D. LeCompte, *Ethnography and Qualitative Design in Educational Research*. New York: Academic Press. 1984.

[41] FabLab@SCHOOLdk. www.fablabatschool.dk, 2018 (accessed 22 October 2018)

[42] C. Bossen, C. Dindler, and O. S. Iversen, Evaluation in Participatory Design: A Literature Survey, In Proceedings of the 14th Participatory Design Conference: Full Papers - Volume 1 (PDC '16). ACM, New York, NY, USA, (2016) 151–160. https://doi.org/10.1145/2940299.2940303

[43] O. S. Iversen, R. C. Smith, and C. Dindler, From computational thinking to computational empowerment: a 21st century PD agenda, In Proceedings of the 15th Participatory Design Conference: Full Papers - Volume 1 (PDC '18), Liesbeth Huybrechts, Maurizio Teli, Ann Light, Yanki Lee, Julia Garde, John Vines, Eva Brandt, Anne Marie Kanstrup, and Keld Bødker (Eds.), Vol. 1 (2018) ACM, New York, NY, USA, Article 7, 11 pages. DOI: https://doi.org/10.1145/3210586.3210592

[44] Pioneruddannelse - Campus Bindslevs Plads. http://campusbindslevsplads.dk/index.php/fablab/om-fablab/pioneruddannelse/, 2018

[45] J. Ritchie & L. Spencer, *Qualitative data analysis for applied policy research*. In A. Bryman and R. G. Burgess [eds.] 'Analysing qualitative data', (pp.173-194). London: Routledge. 1994.

[46] R. W. Revans, *ABC of action learning*. London: Lemos and Crane, 1998.

[47] D. A. Schön, *Educating the reflective practitioner*, San Francisco: Jossey-Bass Publishers, 1987.

[48] FabLearnDK conference. http://fablearndk.blogspot.com/, 2018 (accessed 22 October 2018)

[49] A. Bandura, Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84(2), 191-215. https://doi.org/10.1037/0033-295X.84.2.191, 1977

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We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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