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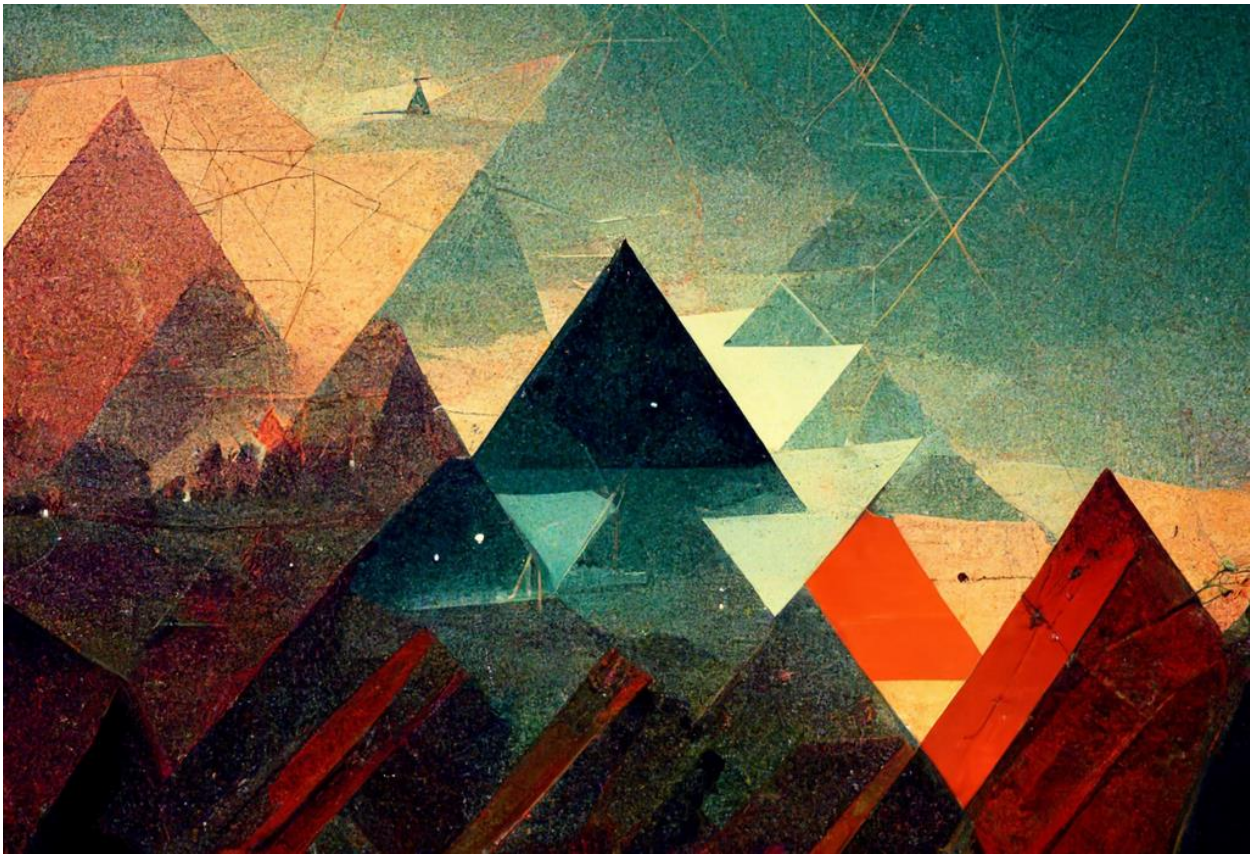

PhD Thesis

Nina Holst Waaddegaard

Integrated STEM Education in Schools

An activity Systems Analysis of potential barriers to implementation

Supervisor: Jan Sølberg

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Content

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Abstracts

English abstract

For many years, educational reforms worldwide have sought to implement and improve integrated STEM education (Science, Technology, Engineering and Mathematics). This is also the case in Denmark, where integrated STEM education has gained momentum in educational policies related to primary and secondary school for at least two decades. However, there is no univocal understanding among stakeholders of what STEM is and what it entails. Even though integrated STEM approaches are an ambition for science education in Denmark, research about how successfully to implement integrated STEM education in comprehensive schools is limited. If we are to achieve more widespread implementation, it is crucial that we understand the potential barriers that impede teachers from adopting integrated STEM approaches.

Based on cultural-historical activity theory, the purpose of this Ph.D. study is to explore the systemic contradictions that mediate implementation of integrated STEM education in comprehensive schools. This, in turn, can help us understand how such systemic contractions pose barriers for more widespread implementation and provide suggestions for ways of overcoming these.

The Ph.D. study is based on a case study of groups of teachers from four different schools participating in the 'Science Marathon' program. 'Science Marathon' is explored as an example of integrated STEM in comprehensive schools. Data for the study was collected through participant observations and qualitative interviews and subjected to thematic analysis. Finally, selected themes were explored using an activity systems perspective on each school.

The study found the following systemic contradictions across the four case schools, (1) approaching integrated STEM as science teaching or interdisciplinary teaching, (2) distinguishing between science and engineering practices, (3) teaching for science competence or content, (4) 21st century skills as relevant but vague goals, (5) inconsistency of integrated STEM object leads to varying teaching practices, and (6) integrated STEM object compatibility with local settings.

These contradictions were present in each of the four schools, but they posed barriers for implementation of integrated STEM to varying degrees dependent on the local school settings. In other words, this study proposes that any attempt to implement integrated STEM needs to consider how these contradictions present themselves in local school settings.

Danish Abstract

På tværs af landegrænser har uddannelsesreformer gennem mange år haft fokus på at implementere og forbedre integreret STEM undervisning (STEM står for 'Science, Technology, Engineering og Mathematics'). Dette er også tilfældet i Danmark, hvor integreret STEM undervisning har indgået som del af uddannelsespolitikkerne relateret til grundskolen og gymnasiet de sidste to årtier. Men der er ikke enighed om, hvad integreret STEM indebærer, og selvom det er en ambition for naturfagsundervisningen, findes der ikke meget forskning om, hvordan integreret STEM vellykket kan implementeres i grundskolen.

Hvis vi skal opnå en mere udbredt implementering af integreret STEM i grundskolen, er det afgørende, at vi forstår de potentielle barrierer, som kan forhindre lærere i at benytte sig af integreret STEM tilgange.

Med udgangspunkt i kultur-historisk virksomhedsteori har formålet med dette Ph.d. projekt været at undersøge de systemiske modsætninger, der medierer implementeringen af integreret STEM i skolen. Dette kan hjælpe os med at forstå hvordan disse systemiske modsætninger kan forårsage barrierer for udbredelsen af integreret STEM og samtidig pege på, hvordan vi kan overkomme dem.

Ph.d. projektet er baseret på et case studie af lærere fra fire forskellige skoler, der deltager i 'Naturfagsmaraton', der undersøges som et eksempel på integreret STEM undervisning i grundskolen. Data blev indsamlet gennem deltagende observationer og kvalitative interviews for derefter at blive udsat for tematisk analyse. Til sidst blev udvalgte tematikker analyseret ud fra et virksomheds systemisk perspektiv på hver skole.

Ph.d. projektet fandt følgende systemiske modsætninger på tværs af skolerne (1) tilgang til integreret STEM som naturfaglig eller tværfaglig undervisning (2) skelnen mellem naturvidenskabelige og engineering praksisser (3) undervisning for naturfaglig kompetence eller viden (4) 21. århundredes kompetencer som relevante men uklare mål, (5) uoverensstemmelse i objektet for integreret STEM undervisning medfører forskellige undervisningspraksisser (6) uoverensstemmelse mellem objektet for integreret STEM undervisning og den lokale skolekontekst.

Disse systemiske modsætninger var tilstede på alle fire skoler, men i hvilken grad de udgjorde barrierer for implementeringen af integreret STEM undervisning afhang af de lokale skoleforhold. Dette Ph.d. projekt viser med andre ord, at et hvilket som helst forsøg på at implementere integreret STEM i grundskolen bør overveje, hvordan disse systemiske modsætninger manifesteres i lokalt.

1. Introduction

My research interest in exploring teachers' perceived challenges and prospects when conducting integrated STEM instruction initially started back in 2015, when I became part of the team conducting a research-based evaluation of the school development project 'ISI2015' (Innovation, Science and Inclusion 2015).

ISI2015 took place in five different schools in Denmark, and was intended to improve students' science and innovation competences by introducing innovation to science instruction. More specifically, the teachers in ISI2015 had to plan and carry out instruction focused on innovative processes, where students worked on solving an authentic and open-ended problem by creating ideas, designing and constructing prototypes as solutions. Moreover, the teachers had to focus on interdisciplinary and student-centred approaches in a project-based learning context.

ISI2015 lasted for six years, and during that period, the participating teachers' perceptions of learning and instruction transformed from focusing on subject content to emphasizing students' learning processes (see Sølberg et al., 2015 for full details). In other words, most teachers involved in ISI2015 developed an understanding of learning outcomes and instructional approaches based on competences rather than content.

However, this transformation did not happen overnight and included many challenges. In fact, the teachers in ISI2015 reported many challenges related to collaboration, school organizations, and even what the students learned from the innovative processes.

Nevertheless, the teachers also experienced that the students developed positively from the learning activities in ISI2015, even though they could not say exactly what they learned.

At the end of the project, the evaluation showed that the students in ISI2015 had developed a range of different learning outcomes, such as abilities to apply scientific knowledge and processes in problem solving, and gained competences such as collaboration, critical thinking, and communication, referred to as 21st century skills. However, it was also reported that the transition from emphasizing subject content to emphasizing competences through innovative approaches to learning was difficult, not just for the teachers involved but for the entire school organization.

Research literature related to implementing a competence-based curriculum supports this notion. For example, Byrne et al. (2013) expressed concerns that teachers experienced a clash between pressures to teach in a competence-based manner, and to provide students with qualifications based on a traditional curriculum and pedagogy. This clash that Byrne et al. (2013) described was also problematized by Dolin et al. (2017), who said that teachers are forced to focus on students' competences in a school system that still emphasizes summative assessments, thereby promoting subject content. Whereas Ropohl et al. (2017) suggested that the challenge related to implementing competence-based approaches to instruction was linked to a school system that historically emphasized subject content. This can explain why it is a challenge for teachers to find ways to implement complex competences, such as 21st century skills across subjects, and master both instruction and assessment strategies supporting students in developing these skills (Voogt & Roblin, 2012). These research perspectives thus suggest that there are substantive conflicts permeating the school system related to implementing competence-based learning goals.

ISI2015 became my stepping-stone to explore the transition process of schools implementing competences as learning goals and approaches to instruction. I chose to focus on this transition in the context of STEM (Science, Technology, Engineering and Mathematics) education, since it has become common worldwide to reform educational systems in order to enhance the national focus on STEM education (Williams, 2011). At the same time, STEM education is recognized as a particularly important educational context for developing competences needed in the 21st century (English & King, 2015). More particularly, I focus on integrated STEM education as an instructional approach that offers teachers the means to provide students with opportunities to develop both disciplinary competences (Couso & Simarro, 2020) and 21st century skills (Bybee, 2010).

From this perspective, it is my hope to contribute with relevant knowledge about how integrated STEM education can be implemented successfully. In this context, my starting point is the science subject 'nature/technology' ('natur/teknologi') for grade level 1-6, which is part of the comprehensive school system in Denmark.

This thesis contributes to the field of science education by examining how schools can implement integrated STEM approaches in classrooms, and what possibilities and challenges characterize this process. It is my hope that this knowledge can inform teachers and teacher educators, and prove valuable for future integrated STEM educational programmes in the Danish comprehensive school as well as other school systems.

The aim of this thesis has been to conduct an open-ended exploration of the Danish comprehensive school system to elucidate how existing school practices have an impact on teachers' ways of adopting an integrated STEM approach in their teaching practices.

This research is particularly relevant in Denmark, as STEM education is a fundamental part of the Danish agenda for science. The Danish school reform of 2014 fundamentally changed the science curriculum for comprehensive school by including competences as learning goals in the curriculum, to both strengthen coherence between the science subjects and strengthen interdisciplinary learning. Moreover, many educational initiatives and programmes being developed and implemented in schools today are based on integrated STEM approaches. Nevertheless, research about how to implement an integrated curriculum and conduct interdisciplinary teaching is still limited (Nielsen et al., 2017).

1.1. Problem statement and research questions

The aim of the PhD project is realized through the following research question:

> *What systemic contradictions mediate the implementation of integrated STEM education in comprehensive schools?*

This overall research question is operationalized through four sub-questions that are addressed by the written papers in this thesis and followed up on in the discussion:

- What characterizes integrated STEM practices when applied in the Danish comprehensive school context? (paper 1).
- How are the teachers' perceptions of important learning goals aligned with integrated STEM educational ambitions? (product 4).
- What existing school structures either support or impede teachers from conducting integrated STEM education in the Danish comprehensive school? (paper 2 and 3).

These research questions set the stage for a detailed description of the teachers' practices by exploring how they perceived integrated STEM approaches, how they planned and conducted teaching, and if and how they collaborated with teacher colleagues in the process. Importantly, I want to identify systemic barriers potentially impeding teachers in implementing integrated STEM approaches, and more importantly, to explain why these barriers exist. To do that, I apply cultural-historical activity theory as the theoretical framework, and activity systems analysis (Engeström, 1987; 2015) as an analytical tool, because this approach is particularly suitable for identifying and describing systemic contradictions and tensions in educational contexts (Yamagata-Lynch, 2010). I therefore apply activity systems analysis to understand and explain the potential barriers related to implementing integrated STEM education in schools as manifestations of historically accumulated systemic contradictions.

Accordingly, I have conducted a qualitative case study of middle school teachers from four different schools participating in the educational programme called 'Science Marathon'

(‘Naturfagsmaraton’). In section 4.2., I describe this educational programme in detail and why I have selected it as case for this study.

1.2. Cohesion between the papers

To understand how the written papers of this thesis are connected, I present a brief overview of how each of them emerged as ideas that built on the results of the former. This is related to the fact that this PhD project from the beginning has been an explorative process of trying to understand how integrated STEM approaches are implemented in comprehensive schools from a teacher perspective, and what is at stake in this process.

1.2.1. Paper 1

Sølberg, J., & Waaddegaard, N. (2019). Hvad ved vi om indsatser inden for engineering i den danske grundskole inden for de sidste 10 år? *MONA – Matematik og naturfagsdidaktik*, 2019(2), p. 31-47

The idea of this article was developed in the beginning of my first year as a PhD student, while I was still in the process of defining my project. The article was written as a collaboration with Sølberg as part of consultant work for a development project called ‘Engineering in the school’ (‘Engineering i skolen’). The development project required a review of educational initiatives related to STEM to inform the design of interventions in the project. Engineering was new to Danish compulsory science education, so the scope of the review was expanded to include all STEM related initiatives, which meant that it was relevant as a vantage point for this thesis.

The article provides a broad overview of the educational field of integrated STEM educational initiatives in Danish schools in the period of 2006 – 2017. By analysing these different initiatives, I discovered that there are many different agendas permeating integrated STEM education, and these initiatives thus aimed at many different goals that sometimes pointed in different directions. This made me curious about what happens, when a broad understanding of integrated STEM education meets the Danish comprehensive school system. The article illustrated that much was at stake for teachers and students when conducting integrated STEM education, and many challenges presented themselves in the wake of this type of instruction.

The realizations from this article helped me to narrow down the field of study and to find a relevant educational programme to apply as an empirical case. It also pointed forward to the next paper in the thesis, focused on the organizational challenges, which I identified as potential barriers in this article.

1.2.2. Paper 2

Sølberg, J., & Waaddegaard, N. (2022). Lærernes udfordringer med kompetenceorienteret naturfagsundervisning. In Fougt, Bundsgaard, Hanghøj & Misfeldt (Eds.). *Håndbog i scenariedidaktik* (pp. 247-257). Aarhus Universitetsforlag.

Based on the results of the first article, I had selected the educational programme Science Marathon as an example of integrated STEM in comprehensive schools to apply as the case to study. Incidentally, Sølberg and I were invited to write a chapter for a book on competence-based education around the time (Fougt, Bundsgaard, Hanghøj & Misfeldt, 2022). I was finishing my initial analysis of the data, and the book was a good opportunity to unfold some of the systemic barriers for competence-based science instruction in the data. However, due to paternity leave I was unable to initiate this article, which led to Sølberg becoming lead author.

In this book chapter, I applied cultural-historical activity theory as the theoretical framework. Using the notion of activity systems as the theoretical approach, I examined each of the four case schools involved in the process of adapting competence-based approaches to STEM instruction in relation to their existing school practices. By analysing each case school as activity systems, I was able to capture what organizational practices provided either support or barriers for teachers' implementation of competence-based approaches to instruction.

The results confirmed that focusing on competence-based learning goals is not only dependent on teachers, but also on the existing school structures and organization. Focusing on how the school settings influenced the teachers' possibilities for conducting competence-based approaches also suggested that there was a tension between different understandings of learning and instruction as an immanent part of the teachers' practices. I decided to explore this issue further in my third paper.

1.2.3. Paper 3

Waaddegaard, N., & Sølberg, J. (submitted to the journal 'Mind, Culture and Activity'). A cultural-historical perspective on integrated STEM education in Danish middle schools.

This article is an in-depth cultural-historical activity theoretical analysis of two of the four case schools involved in this study. I examined these two schools as activity systems, which enabled me to analyse how each component of the activity system shaped the teachers' activities of implementing integrated STEM approaches in the context of the Danish comprehensive school system. In this article, I developed an elaborated understanding of systemic contradictions as a driving force in activity systems.

This article is the methodologically most elaborated account, showing how existing school practices affect what teachers can achieve when adopting an integrated STEM approach. The results of this article identified barriers related to the teachers' disciplinary understandings as manifestations of a systemic contradiction within the school system.

1.2.4. Paper 4

Waaddegaard, N. (submitted to 'International Journal of STEM Education'). Integrated STEM education: what are the teachers' perceptions of important learning goals?

This article takes its departure from the in depth analysis of two very different activity systems in the third paper, as well as results from the first paper that indicated that integrated STEM initiatives can have many different learning outcomes for students. I wanted to explore the object of activity (the intended goals produced into an outcome) in more detail, as the earlier analyses had shown that the teachers involved had many differing ideas about the purpose and aim of Science Marathon, as well as science education in general. I therefore did an analysis of the teachers' accounts of relevant learning goals in Science Marathon, and compared how they shared similarities with learning ambitions in integrated STEM education. This article is the most theoretically elaborated account of STEM literacy, 21st century skills and disciplinary competence as potential learning in integrated STEM education.

Together, these four papers cover several key aspects of what it means to conduct integrated STEM education in Danish schools, and what challenges and prospects teachers experience in this process. These aspects include an overview of integrated STEM activities in Danish comprehensive schools, organizational aspects affecting implementation of competence-based approaches, systemic contradictions engrained in the school system, and teachers' accounts of what they perceive as important learning goals for integrated STEM education.

2. Integrated STEM Education – theoretical starting point

Placing this PhD project in the research field of integrated STEM education serves more than one purpose. First, it provides an opportunity to give an overview of the research literature of integrated STEM education. Second, it creates an opportunity to discuss the relevance of integrated STEM in the Danish comprehensive school system. Third, it presents the foundation of my theoretical understanding of integrated STEM education from which my empirical findings are analysed and discussed.

2.1. The STEM acronym

I start by outlining how the STEM acronym came into existence. Then I describe some of the many different meanings of STEM education, to arrive at integrated STEM education as one particularly important way to approach STEM education.

Mohr-Schroeder et al. (2012) described that US policies in the 1950'es began to increase emphasis on the STEM disciplines because of a threat to national security during the Sputnik era. Based on a competitive drive, NASA was formed and in the years afterwards, 80,000 students graduated with engineering degrees in the US annually. Ever since, US policies and curriculum reforms have prompted a focus on the STEM disciplines (Mohr-Schroeder et al., 2015).

However, it was not until the 1990s that the National Science Foundation (NSF) brought the acronym STEM to light, although it was first called SMET (Blackley & Howell, 2015; Bybee, 2010). Ever since, any policy or practice involving one or more of the STEM disciplines has used the STEM acronym indiscriminately, according to Bybee (2010). This underpins the fact that there is until this day, many different perspectives of what the STEM acronym means.

The heritage from the Sputnik era is still apparent today, as STEM policies still emphasize STEM education as a means to improve the STEM workforce (Mohr-Schroeder et al., 2015; Siegel & Giamellaro, 2020). Most countries therefore have developed specialized programmes and initiatives focusing on STEM (Slavit et al., 2016).

This is also the case in Denmark, where the Ministries of Industry, Business, and Financial Affairs, of Higher Education and Science, and of Children and Education established the 'Technology Treaty' ('Teknologipagten') in 2018. The purpose of the Technology Treaty is to gather relevant stakeholders within various STEM fields, to bring into focus the lack of Danish Citizens with STEM competences in order to meet a future recruitment challenge for STEM occupations. To achieve this purpose, the advisory board assigns funding to STEM-related projects. The Technology Treaty consists of more than 100 projects focused on improving STEM teaching, recruiting more girls/women in STEM education/occupations, strengthening collaboration between education and business and upgrading teachers' and educators' competences in teaching STEM (Teknologipagten, n.d.).

Nevertheless, despite how much momentum the STEM movement has gained all over the world, and despite the huge amount of STEM funded projects, there is still no consensus about the meaning of the acronym (Wong et al., 2016). Accordingly, the interpretation of STEM education varies across educational settings (Wong et al., 2016; Bybee, 2010; Blackley & Howell, 2015; Sanders, 2009; El Nagdi et al., 2018).

Tytler (2020) described the variety of forms that STEM in education could take. This included;

- attracting student interest by promoting mathematics and science;
- integrating engineering design with mathematics and science;
- promoting digital technologies as a separate subject or integrated throughout the curriculum;
- combining two or more of the STEM disciplines through interdisciplinary project work focusing on problem solving real-world challenges;
- emphasizing STEM professional work by creating relationships with STEM industries;
- focusing on creativity and design thinking through STEAM;
- preparing students for the 'world of work in the twenty first century' (Tytler, 2020, p. 23).

Although this list of various interpretations of STEM education is not exhaustive, it does illustrate that there are many different agendas and stakeholders involved in STEM education. This can explain why there exist a general confusion related to how to teach STEM, how to progress in STEM education and how to assess STEM learning (Williams, 2011). In fact, Williams (2011) inferred that STEM education lacked an educational reason for combining the STEM disciplines and characterized it as a necessity to clarify the theoretical assumptions underpinning it. In similar ways, Kloser et al. (2018) inferred that the pedagogical components of STEM education were surrounded by ambiguity.

This lack of consensus regarding STEM education has led to discussions about whether it is even necessary to have standardized understandings of what ambitions to achieve through STEM education. For example, Hourigan et al. (2021) problematized the idea of uniform standards of STEM goals and approaches, since STEM education is implemented in such various contexts. Instead, they suggested, that those working within the same education system needed to co-

construct a shared vision that gave all learners opportunities to achieve STEM related goals. Holmlund et al. (2018) went further by saying that even educators working in the same context tended to make sense of STEM education differently.

However, this lack of consensus about STEM education makes the ambitions to achieve and the learning goals to aim for unclear. According to Roehrig et al. (2021b) consequently, we are not able to draw any conclusions across studies about students' learning outcomes in STEM education.

2.2. Integrated STEM Education

I will now describe how integrated STEM education came into existence and present the overall definition that I subscribe to in this study.

The Framework for K-12 Science Education (2012) and Next Generation Science Standards (2013) in the US for the first time explicitly integrated engineering, technology, and mathematical thinking into K-12 science education, which resulted in what is known as integrated STEM education (Roehrig et al.,2021a, p. 2). According to Blacklay and Howell (2015, p. 107), the rise of integrated STEM education was an attempt to develop an approach for converting the political agenda about STEM, which was infused with economic rationales, to a viable pedagogy and curriculum.

Although integrated STEM is a relatively new educational concept, curriculum integration is not. It dates back more than 100 years (Czerniak, 2010) to the progressive education movement in the early 1900s (Drake & Reid, 2017; Roehrig et al., 2013). As such, there are strong resemblances between progressive education and the pedagogies that characterize integrated STEM education. For example, integrated STEM education is an attempt to confront a traditional school curriculum with a segregated and discipline-based structure as "an artifact of history" (Moore & Smith, 2014, p. 7). To do so, the integrated STEM curriculum should reflect the "natural interconnectedness of the four STEM components in the real world" (Roehrig et al., 2012, p. 32). This makes it crucial to understand how the STEM disciplines are connected.

However, the lack of clarity regarding what counts as integrated STEM education makes this difficult. For example, it varies between definitions of integrated STEM how many STEM disciplines need to be included in an instruction unit to define it as integrated STEM (Moore et al., 2020).

Sanders (2009) was among those believing it to be enough to integrate the learning goals of at least one of the STEM disciplines into another STE(A)M disciplinary curriculum to define it as integrated STEM:

> “integrative STEM education includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects” (Sanders, 2009, p. 21).

I subscribe to Sanders’ (2009) understanding of integrated STEM. It is not so much which of the STEM disciplines you integrate in the curriculum that defines if it is integrated STEM, as it is about the approaches to instruction and learning applied. Because, as Johnson (2013, p. 367) asserted: “integrated STEM education is more than curriculum integration”. For example, it is about *how* you combine the STEM disciplines in the curriculum.

2.3. Approaches to curriculum integration

In this chapter, I start by describing STEM education on a spectrum of different degrees of integration, to arrive at three different approaches to STEM integration. Then I compare with the Danish comprehensive school system by addressing a related discussion within the science educational field about whether to target science as an integrated curriculum or as separate subjects.

Nadelsen & Seifert (2017) envisioned integrated STEM education on a spectrum “with segregated domain-specific STEM at the one end of the spectrum”, and “integrated domain general STEM at the opposite end of the spectrum” (Nadelson & Seifert, 2017, p. 1). On the segregated end of the spectrum, STEM is used indiscriminately with the individual disciplines, even though they are taught separately. This traditional way of organizing the curriculum is referred to as the “siloed treatment” of STEM (Hourigan et al., 2021, p. 19), or the “individual silos” of STEM” (Bybee, 2010, p. 31). This curriculum organization is the prevailing practice in most US schools, according to Sanders (2009).

On the integrated end of the STEM spectrum, curriculum integration is envisioned in various ways, for example as multidisciplinary, interdisciplinary or transdisciplinary (English et al., 2017; Tytler et al., 2021). However, there exist many different taxonomies for curriculum integration that represent different degrees of integration, and as such it can be difficult to distinguish between them (Klausen, 2011). This is potentially problematic because when using different terms synonymously it tends to result in disagreements related to what curriculum integration is really about (Czerniak, 2010).

This lack of agreement about the nature of integration emphasizes the importance of defining the approaches to integration applied in this thesis. Accordingly, I apply an understanding of curriculum integration as a continuum of multidisciplinary, interdisciplinary, and transdisciplinary integration (Drake & Reid, 2020). These three forms represent different degrees of integration, but are recognized as equally valid approaches.

Drake and Reid (2020, p. 2) define a multidisciplinary curriculum as;

> "Content, instruction and assessment are specific to each discipline. However, the disciplines share a common theme or concept. Students study the topic or theme through the separate lens of each subject. Connections among the disciplines may or may not be made explicit by the various disciplinary teachers…"

In a multidisciplinary curriculum, the disciplinary subject borders remain distinct. Advocates of a multidisciplinary curriculum regard this approach as the best way for students to understand how the disciplinary contents from each STEM discipline are connected (Roehrig et al., 2021b). By leaving each discipline identifiable in the curriculum (Roehrig, 2021a) they want to respect the integrity of the disciplines (Williams, 2011; English, 2017). This was the case when Hourigan et al. (2021) reported from a study about STEM teachers in Ireland, and found concerns among these teachers that resonated with the arguments for a multidisciplinary curriculum. They considered curriculum integration as a meaningful endeavour, but they also regarded students' learning of conceptual knowledge within the individual STEM disciplines to be important too. Therefore, the teachers preferred to first build students' disciplinary content knowledge, and then apply it in a STEM integrated context (Hourigan, 2021, p. 19).

Drake and Reid (2020, p. 2) defined an interdisciplinary curriculum as:

> "Disciplines remain somewhat distinct, but their connections are stronger and made explicit. Boundaries are blurred when subjects are organized around a key interdisciplinary concept such as sustainability, or around complex interdisciplinary skills such as critical thinking or competences such as intercultural competence. Interdisciplinary projects provide a context for exploration and blending the subjects. Often interdisciplinary team members share instruction and assessment to ensure that disciplinary standards are met."

Whereas a transdisciplinary curriculum is the most integrated form:

> "Students begin with an authentic real-world issue rather than with the disciplines. Students' own interests often generate the starting point" (Drake & Reid, 2020, p. 2).

This form of curriculum integration dissolves disciplinary borders because the problem defines the context of exploration rather than the subjects involved. The problem is characterized by being complex, open-ended, relevant and authentic. In the problem solving process, students can then apply subject content if relevant for the solution. According to advocates of a multidisciplinary approach, a complete fusion of the disciplines can result in a shallow understanding of disciplinary content (Roehrig et al., 2021b).

McDonald (2016) described interdisciplinary and transdisciplinary approaches to STEM integration as the “ideal approaches to implementing authentic STEM schools” (McDonald, 2016, p. 531). Whereas Nadelson and Seifert’s (2017) definition of integrated STEM education resonated with the transdisciplianry approach by emphasizing the context of the problem rather than each discipline:

> “We define integrated STEM as the seamless amalgamation of content and concepts from multiple STEM disciplines. The integration takes place in ways such that knowledge and process of the specific STEM disciplines are considered simultaneously without regard to the discipline, but rather in the context of a problem, a project, or task” (Nadelson & Seifert, 2017, p. 1).

Within the science educational agenda for comprehensive schools in Denmark, there are both advocates of a segregated curriculum and of an integrated curriculum. For years, several science education researchers have pointed out several critical issues related to a sharp separation of the science disciplines into separate subjects (Andersen et al., 2003; The Ministry of Education, 2006; Arbejdsgruppen, 2008; NTS Centeret, 2013; Bohm et al., 2017). They argued that it prevented interdisciplinary teaching and learning, which was crucial to create synergies between the subjects and to focus on interdisciplinary learning.

Throughout the years, these committees all recommended building a more coherent science education by defining competences as learning goals, to ensure progression and synergies between the science subjects and softening the disciplinary boundaries. In 2017, experts from various STEM domains such as education, research and businesses were commissioned by the Ministry of Children and Education to develop a national scientific strategy. In the report (Bohm et al., 2017), the appointed committee recommended establishing an integrated science subject to promote meaningful learning through problem-based approaches to instruction in comprehensive schools. However, the former Minister of Children and Education disagreed with the committee and instead commissioned a new advisory group, that contrary to the recommendations in the strategy recommended promoting teaching in the separate subjects and strengthening standardized tests (Dolin, 2018). Moreover, the minister also initiated what is now known as the ‘Science ABC’ (‘Naturvidenskabens ABC’), an attempt to define 10 canonical areas of content for science education (Andersen, 2021). This illustrates that both segregated and integrated curriculum initiatives co-exist as different educational agendas within the same educational system.

One reason why many still advocate a segregated curriculum is that it is not conclusive that curriculum integration results in improved student learning outcome. Czerniak (2010) described that it is debated whether integrated approaches are more effective than discipline-based ones, since only a few empirical studies can support this assertion. However, she also asserted that one key reason for this is related to the confusion about what curriculum integration really means. Another reason concerns if it is possible to maintain the identities of each of the STEM disciplines in an integrated curriculum.

2.4. Disciplinary representation

In this chapter, I address concerns expressed from within each disciplinary field of science, technology, engineering and mathematics related to how the disciplines are represented in STEM policies and curricula and compare it to the Danish educational agenda.

From within each STEM disciplinary field there are stakeholders that express concerns related to whether "the intellectual integrity" (El Nagdi et al. 2018, p. 3) of the discipline they represent is preserved. This is an important question, since the loss of epistemic integrity can "deprive participants of the epistemic knowledge attaching to the distinctive practices in the individual disciplines" (Tytler et al., 2021, p. 272). According to Couso and Simarro (2020, p. 25) this makes it necessary to consider the nature of each of the disciplines involved to avoid an 'epistemic malpractice'. They suggested to include disciplinary competences from each of the integrated disciplines as learning goals, to avoid this scenario. They argued that this would not only meet the concerns, but also produce several educational benefits. For example enabling students to develop a deeper understanding of how the disciplines are connected by comparing their differences and commonalities. The inclusion of disciplinary competences of each of the integrated STEM disciplines would thus address the lack of coherence in the curriculum.

In Denmark, this was one of the main reasons why stakeholders within the field of science education research pleaded for competences to be inserted as learning goals in the national curriculum for comprehensive school (see for example Andersen et al. 2003), which was implemented as part of a school reform of 2014.

But in many national STEM policies and curricula this is often not the case. STEM education is most associated with science and mathematics, ignoring engineering and technology (McDonald, 2016; Bybee, 2010). In fact, science is the dominating discipline in STEM educational policies, while the other STEM disciplines most often take supporting roles to promote science teaching and learning (Wong et al. (2016). STEM education is therefore associated with scientific literacy as the ultimate educational purpose in many nations (English, 2017), suggesting that the science disciplinary field dominates what goals are to be achieved through integrated STEM education.

This is also the case in Denmark. Seidelin and Larsen (2021) described how several Danish municipalities implemented STEM strategies with the political aim of creating better coherency within the science subjects in the entire educational sector.

Contrary to science, technology is often overlooked. Williams (2011) problematized that technology risked merely acting as a tool to achieve goals in science and mathematics. According to Roehrig et al. (2021b), technology is rarely treated explicitly in definitions of integrated STEM education. This has to do with the fact that it is unclear what technology even means in educational settings. For example, a study reported that teachers had a limited understanding of the nature of technology (Wang et al., 2011). Another study questioned why educators only seemed to view technology as "the use of educational technology" not recognizing that technology consists of a body of knowledge and practices (Kelley & Knowles, 2016, pp. 5-6). Instead, the meaning of technology in educational settings is polarized between "hardware and software with which one supports the teaching and learning process", or "the collection of tools (…), used by humans" (Blackley & Howell, 2015, p. 105). The perspective of the arts is neglected, even though they can bring to bear the purposes of technology (Kelley & Knowles, 2016).

In the Danish comprehensive school, technology is not a separate subject in the curriculum yet. However in 2018, The Danish Ministry of Children and Education initiated a national experiment called The 'Tech-experiment' ('Teknologiforsøget'), with the purpose of testing 'technology comprehension' as a subject in the curriculum for comprehensive schools (Teknologforståelse i folkeskolen, n.d.). Accordingly, technology comprehension was implemented both as a separate subject and as integrated into other subjects, such as science and mathematics. 46 schools participated nationwide to achieve the educational goal of developing students' critical thinking related to technology (EMU, June 2022). However, Nielsen and Sillasen, (2020) criticized the Danish Ministry of Children and Education for an insufficient definition of technology in the Tech-experiment. They suggested that if the subject technology comprehension was to be implemented in the national curriculum beyond the trial period, it was crucial to address the need for; 1) a clear definition of technological literacy, 2) a clear definition of technology in STEM, and 3) a clear definition of technology. Considering these crucial needs, it was not surprising that the results of the evaluation of the Tech-experiment found that the teachers involved expressed difficulties in understanding how to teach technology and requested more teacher training. It is yet unknown whether technology understanding will be implemented as a subject in the comprehensive school (EMU, October 2021).

In contrast to technology, engineering has a central role in integrated STEM education as a context integrator (Roehrig et al., 2021b), with engineering design processes shaping the approaches applied in integrated STEM education. For example, English et al. (2017) stressed that engineering provides an engaging problem context. Rightly, engineering is characterized as “an umbrella and a context for integration” by El Nagdi et al. (2018, pp. 20-21). They also described engineering as “a systematic process for solving problems based on scientific knowledge and models of the material world” (El Nagdi et al., 2018, p. 3).

In this iterative process of going back and forth between evaluating and improving on solutions (Margot & Kettler, 2019), the engineering design process can promote several complex competences. For example, Dare et al. (2018) argued that engineering supports development of problem-solving skills, teamwork and collaboration skills. Engineering can also improve student motivation to learn. For example, Stohlmann (2019) supported that engineering practices could increase student motivation in science and mathematics. Engineering is therefore central for integrated STEM education, as it is associated with the context and the means to achieve learning goals in mathematics and science. Because engineering is not a traditional school subject it is often placed within science classes, and is therefore often perceived as an application of science (Kloser et al., 2018). Commenting on this, Cunningham & Kelley (2017) admitted that engineering design processes can be applied as a method to support teaching science, but ideally its’ unique epistemic features had to be considered too by educators. However, Kloser et al. (2018) found that this was rarely the case. Instead, engineering was the discipline most often missing in teachers’ conceptions of integrated STEM.

In Denmark, engineering is not a separate subject in the curriculum for comprehensive education. However, in 2018, an educational programme called ‘Engineering in the School’ (‘Engineering i Skolen’) developed an engineering approach to be implemented in the science subject. It was based on an engineering design process, structured in iterative sub-processes of understanding and investigating a challenge, creating ideas for solutions, concretizing, constructing, improving the solution, and finally presenting it (Auener et al., 2018). ‘Engineering in the school’ has a mission to improve student learning in STEM in comprehensive schools (Engineer the future, n.d.). Hereafter, the engineering approach developed by the programme was implemented in the teacher instructions for the national science curriculum as a problem-based approach to support learning in science (The Ministry of Children- and Education, 2019). Complying with the STEM literature, engineering was described as an approach helping to achieve science learning goals in the Danish comprehensive curriculum.

From the disciplinary field of mathematics, it is questioned whether mathematics is granted a proper place in the integrated STEM curriculum (English, 2017), that allows it to maintain its disciplinary integrity. This is because mathematics is often applied as a tool with known processes instead of developing new mathematical insights (Tytler et al., 2019). Roehrig et al. (2021a) supported this assertion by reporting that mathematics only represented 10 % of the concepts to be learned in a series of integrated STEM curricula. Mathematics thus tends to be backgrounded as a tool with only few or no learning goals (Roehrig et al., 2021b). One solution is to make the mathematical connections more explicit. However, Walker (2017) said that it was particular difficult to integrate mathematics in STEM lessons because it was difficult to identify grade-level appropriate mathematics content that aligned with the chosen topic. To meet this challenge, Walker (2017) then suggested defining explicit learning objectives for each of the STEM disciplines involved and Stohlmann (2019) urged mathematics teachers to maintain focus on mathematics during team planning. If these concerns are met, integrated STEM activities can increase student interest in mathematics (Stohlmann, 2019).

In Denmark, mathematics represents the largest subject of the four STEM disciplines in the curriculum in terms of allocated time per school year, followed by science. However, due to the large extent of mathematics and its importance in the Danish curriculum, it is beyond the scope of this thesis to account for the subject here.

2.5. What are the goals in integrated STEM education?

In this chapter, I will briefly touch upon some of the goals of STEM education. For an elaborated account, I refer to the fourth paper of this thesis (Waaddegaard, submitted) where I describe STEM literacy, and how to achieve this educational purpose by aiming for 21st century skills and disciplinary competences.

Different agendas permeates STEM education. Accordingly, “goals for an effective STEM instruction have been vigorously discussed” (Wang et al., 2011, p. 3). While the STEM “wish lists of goals” was long, but often undefined (Williams, 2011, p. 31). Many of these inconsistently defined goals pose a risk to implementation:

> “Current STEM skills are inconsistent and not specific enough to inform education and skill policies and initiatives, potentially leading to a number of unsubstantiated and uncoordinated responses” (Siekmann & Korbel, 2016, p. 8).

The prevailing imperative permeating STEM education is based on vocational and economic rationales. From this perspective, STEM education relates to vocational and economic goals. Education becomes the effective means to support economic growth and national competitive advantages by supplying candidates to a STEM skilled workforce. Accordingly, improving STEM education is a strategy to avoid STEM labour shortages in the future, by providing students with desired STEM skills (Blackley & Howell, 2015; English et al., 2017; El Nagdi et al., 2018; Kloser et al., 2018). These rationales surround STEM education with a ‘rhetoric of crisis’ (Blackley & Howell, 2015, p. 109).

However, this narrow understanding of STEM as a workforce agenda has met plenty of resistance within STEM education and research fields. For example, in Denmark it is discussed if Danish industry and stakeholders from the educational domains have uncritically adopted the ‘US crisis discourse’ about STEM education (Schmidt, 2019, p. 71). According to Schmidt (2019) the predominating crisis rhetoric potentially represses the foundational democratic values of the Danish educational system.

But, this is not the only understanding of integrated STEM. The educational imperative of integrated STEM is focused on promoting STEM literacy, meaningful learning and continued motivation to learn (Zollman, 2012). For example, McDonald (2016) described in a review that technology and engineering were being integrated in K-12 schools with the goal to increase student motivation and interest in STEM (McDonald, 2016). In 2018, Kloser et al. studied middle grade teachers’ conception of STEM and found that one of the most frequent views about STEM goals held by teachers was that it could promote student interest and engagement in STEM. From this perspective, the ultimate purpose with integrated STEM is to achieve STEM literacy.

2.6. Integrated STEM approaches

Even though converting STEM to integrated STEM did not create consensus about how to teach and what to learn in this process, there are some basic principles constituting an integrated STEM approach (Thibaut et al., 2018, p. 2). Thereby, “STEM remains an ill-defined but principled construct”, as Siegel & Giamellaro put it (2020, p. 743). I will now account for these basic pedagogical principles and approaches to teaching.

Integrated STEM instruction oppose traditional instructional approaches characterized by teacher-centred pedagogies and focus on acquiring subject content. There are plenty examples illustrating this point. For example, McDonald (2016) described that integrated STEM teaching needed to be altered from traditional, teacher-centred approaches. Sias et al. (2017) opposed what they called a "traditional paradigm" where the teacher and students' roles were dispenser and receivers of knowledge, respectively (Sias et al., 2017, p. 227). Kloser reported in 2018 that their studied teachers consistently interpreted STEM education as instruction going beyond traditional classroom interactions (Kloser et al. 2018, p. 345). Bybee (2010) emphasized that integrated STEM addressed a competence-based approach to problem solving, and thereby did not focus covering subject content.

In this study, I rely on Thibaut et al. (2018) who constructed a framework for integrated STEM instructional practices. This framework consists of five distinctive but related principles of what they deemed as essential parts of teaching integrated STEM:

> "Integration of STEM content, problem-centred learning, inquiry-based learning, design-based learning and cooperative learning" (Thibaut et al., 2018, p. 8).

Even though some of these principles partly overlap, they also consist of distinct characteristics. Thibaut et al. (2018) also referred to other more overarching pedagogical principles, including student-centred pedagogies and 21st century skills.

As an overarching principle, student-centred pedagogies regard students as active learners constructing and interpreting knowledge (Drake & Reid, 2020). Thus, integrated STEM instruction needs "to provide students with opportunities to construct new knowledge and problem-solving skills" (El Nagdi et al., 2018, p. 4).

Moreover, applying student-centred pedagogies creates opportunities for students to develop 21st century skills (Roehrig et al., 2021a; Bybee, 2010). Thibaut et al. (2018) refer to the complex competences, knowledge and skills that are needed to meet the demands of the 21st century, and include creativity, innovation, critical thinking, problem solving, communication and collaboration. I refer to paper 4 (Waaddegaard, submitted) for an elaborated definition of 21st century skills.

Following Thibaut et al. (2018), the first principle of integrated STEM instruction is to integrate STEM content by connecting learning goals, content and practices from the STEM disciplines. Moore et al. (2020) asserted that connecting the disciplines was a main reason for integrating STEM, because they shared so many of the same ideas, practices and conceptual structures. There exist several ways to make connections between the STEM disciplines (Thibaut et al., 2018). As accounted for in section 2.3., applying different forms of curriculum integration can achieve this purpose.

The second instructional principle of integrated STEM is that it is a problem-centred approach. It indicates that the learning environment should enable students to engage “in authentic, open-ended, ill-structured, real-world problems to increase the meaningfulness of the content to be learned” (Thibaut et al., 2018, p. 8). According to Kelley and Knowles (2016, p. 9) learning grounded within a situated context is authentic, relevant for the learner and representative of actual STEM practices. In fact, Roehrig et al. (2021b) argued, it was necessary that learning focused on solving real-world problems to consider it integrated STEM education. This means that integrated STEM is an attempt to make learning meaningful by connecting disciplinary STEM knowledge with personal and real-world experiences (Wang et al., 2011, p. 3). To achieve this, students need learning experiences in a real-world situation instead of learning isolated facts (Roehrig et al., 2012).

The third instructional principle is inquiry-based learning. Approaches that engage students in posing questions, experimenting and participating in hands-on activities to promote knowledge construction (Thibaut et al. 2018). Especially in science, inquiry is crucial and has a long history in science education. It involves engaging students in asking scientific questions, giving evidence and forming explanations from evidence (Guzey et al., 2020, p. 66).

McDonald (2016) claimed that inquiry-based learning approaches were vital to integrated STEM instructional practices and described them as effective ways to enhance students’ abilities to pose questions, solve problems, interpret data, form explanations, and communicate findings (McDonald, 2016).

The fourth principle is design-based learning. Using open-ended design challenges enables students to learn engineering design processes and practices, and deepen their disciplinary understanding (Thibaut et al., 2018, p. 7). The literature often highlight engineering design processes as the ideal context to engage in integrated STEM learning. For example, Moore & Smith (2014) described quality integrated STEM learning to include engineering design challenges. Margot and Kettler (2019) argued that the basis for a STEM pedagogy is the engineering process, where students learn by doing and develop understanding as they refine their ideas. Kelly and Knowles (2016) also proposed engineering design as an ideal platform for STEM learning.

Finally, cooperative learning is the fifth principle for integrated STEM instruction (Thibaut et al., 2018). It provides students with opportunities to collaborate with each other through teamwork. Even though cooperative learning is a common trait about integrated STEM instruction, not many texts explicate how to organize the teamwork according to Thibaut et al. (2018). However, Wieselmann et al. (2021) did exactly that when they conducted a study about students' small group activities and teamwork in STEM instructional units. They concluded that even though small group activities have potential to promote collaboration among students, this often does not happen without the support of teachers. They inferred it was crucial to understand how to support student participation in small group STEM activities given its prevalence, and suggested offering support in developing group norms, tracking student progress on open-ended activities, and in managing time.

These reported approaches to instruction and learning form the basic principles of an integrated STEM instructional approach applied to this study. They have in common that they are founded on social constructivism perspectives on learning (Thibaut et al., 2018) and promote competence-based learning (Bybee, 2010).

However, applying these approaches is easier said than done. This makes it crucial that teachers possess the skills, attitudes and knowledge necessary.

2.7. Teacher skills

Implementing integrated STEM in schools is a demanding task imposed on teachers. They need certain attitudes and skills to be successful in this endeavour. In this chapter, I focus on some of the teacher requirements for conducting an integrated STEM approach.

First, teachers need skills to guide students in student-led process: "teachers have to be able to step out of the director role and allow students to find their own way during the lesson, which might involve unexpected directions" (Margot & Kettler, 2019, p. 12). Nadelsen and Seifert (2017, p. 3) described that this required a "growth mindset" if you were to be efficient in the role as a facilitator of learning. This corresponded with El Nagdi et al., (2018, p. 11) who studied teachers' identity as STEM teachers. They discovered that the teachers regarded their identity as STEM teacher as a continued learning process that required of them to be "flexible, open to change, collaborative, problem-solvers, and aware of the recent trends in teaching and learning".

Another important requirement is to consider teacher collaboration when planning an integrated STEM instructional unit. Even though it is possible for a single teacher to teach all four disciplines in a "standalone STEM subject" (El Nagdi et al., 2018, p. 3), it is a difficult way to proceed. Sanders (2009) problematized that this implementation model demanded that the teacher had a huge amount of content knowledge and pedagogical content knowledge from each discipline successfully to do it alone. Instead, it is more productive for teachers across STEM disciplines to work together to address integrated STEM. According to El Nagdi et al. (2018), a teacher's willingness and ability to collaborate might be one of the most crucial characteristics of a successful STEM teacher. Because even if a single teacher is unwilling or unable to collaborate, it affects the rest of the STEM teacher team.

It also requires certain attitudes of teachers to be successful. For example, STEM teachers must to be confident and willing to teach using an integrated approach (English, 2017). This perspective is supported by Nadelson and Seifert (2017), who asserted that teachers cannot support an integrated approach if they lacked confidence.

Teachers' lack of experience with integrated STEM can explain why they lack confidence to teach it. For example, Hourigan et al. (2021) illustrated the differences between inexperienced and experienced STEM teachers' conceptions of STEM education. Whereas inexperienced teachers had limited conceptions of STEM, the experienced STEM educators had much more robust conceptions. Sias et al. (2017) also contended that prior experience of implementing integrated STEM education was crucial if teachers were to comprehend how to address integrated STEM in their lessons. Whereas Margot and Kettler (2019) concluded that by participating in STEM professional learning courses, teachers increased their enthusiasm for teaching integrated STEM.

This point to the importance of teacher training to improve on teachers' knowledge, skills and attitudes towards teaching integrated STEM approaches. Kelly and Knowles (2016) suggested that professional development for in-service teachers should provide a coherent conceptual framework of how to approach integrated STEM. Likewise, Kloser et al. (2018) recommended professional development providing a coherent vision of integrated STEM education. Whereas Nadelsen et al. (2013) reported from a study indicating even a relatively short professional development intervention with a duration of three days could influence teachers' confidence and efficacy in teaching STEM. Margot and Kettler (2019) suggested that professional development needed to aim for teacher teams as target groups instead of individual teachers.

Although the individual teachers' attitudes and skills play a significant role related to implementing integrated STEM in schools, existing school practices also play a crucial role since they can both support or prevent implementation.

2.8. School Barriers for Implementation

To implement integrated STEM education successfully in schools we need to address and overcome the school barriers that prevent teachers from conducting integrated STEM approaches in classrooms. In this chapter, I focus on some of the barriers that impede teachers from applying integrated STEM approaches. Czerniak (2010, p. 551-552) describe such barriers as a curriculum organized as separate subjects, lack of access to curriculum materials, lack of instructional time, and standardized tests covering separate subjects and not interdisciplinary skills.

One of the most crucial barriers is the discrepancy between a traditional, compartmentalized curriculum and an integrated STEM curriculum. In fact, the current organization of the school curriculum is an important reason why “STEM initiatives have failed, and continue to fail” (Blackley & Howell, 2015, p. 106). The STEM disciplines have been organized as separate disciplines in schools for so long that “it will take a lot more than a four-letter word to bring them together” (Sanders, 2009, p. 21). Hence, the traditional curriculum is “remarkably resilient,” to reforms (Williams, 2011, p. 26). English et al. (2017) even questioned the feasibility of realizing integrated STEM in classrooms as long as the current organization of the curriculum was not changed. Kelly and Knowles (2016) also expressed their concerns about rigid curriculum structures, and warned about “jeopardizing the entire STEM movement” (Kelly & Knowles, 2016, pp. 9-10). In 2018, Holmlund et al. (2018) examined differences between teacher conceptualizations of STEM within STEM-focused schools and more traditional schools. They concluded that teachers in more traditional school settings were less likely to continue to pursue STEM teaching as willingly as teachers from STEM-focused schools. This suggested that STEM-focused schools had made necessary changes.

Another important barrier for implementation is the lack of relevant teaching and learning resources that impede integrated STEM implementation in schools (McDonald, 2016). For example, Stohlmann et al. (2012) asserted that implementing integrated STEM was a challenge simply because it demanded considerably more resources than traditional instruction. This included, instructional materials and tools (Bybee, 2010; Margot & Kettler, 2019; Stohlmann et al., 2012), technology tools (Margot & Kettler, 2019), and guidelines and models about how to teach integrated STEM (Wang et al., 2011; Roehrig et al., 2012).

Time constraints also play a crucial role preventing widespread implementation. For example, Roehrig et al. (2012) described that time constraints impeded teachers from including an engineering design process to their coursework. This is related to Tytler’s (2019) point that there is an increased workload teaching integrated STEM that demanded extra time. Accordingly, school administrators play an important role in supporting teachers with sufficient time for collaboration and joint planning of integrated STEM teaching (Stohlmann, 2019; Kloser et al., 2018).

Another major challenge to overcome is inadequate assessment practices. Falloon et al. (2020, p. 378) expressed concerns about the discrepancies between teachers being urged to explore interdisciplinary approaches, while still having to assess students’ STEM achievements as separate disciplines using standardized testing. Dare et al. (2018) problematized insufficient assessments as a major obstacle preventing widespread implementation. The current assessments available are insufficient as most of them emphasize subject content over interdisciplinary STEM competences and 21st century skills:

> “STEM skills and knowledge cannot be directly measured by current discipline-specific classifications” (Siekmann & Korbel, p. 19).

To align assessment practices with external learning standards, Nadelson and Seifert (2017, p. 3) urged to restructure the curriculum and on that occasion shift assessment practices focused on “student learning from knowledge and facts to application and performance”. Margot and Kettler (2019) added that the field of integrated STEM education in the future needed to focus on formative assessment strategies.

Together, these school barriers create a gap between integrated STEM as envisioned and what teachers are able to realize in classrooms. Bybee (2010, p. 31) described this gap as

“the power of STEM … diminishes quite rapidly as one moves away from national policies and towards the realization of STEM in educational programs”. Whereas Dare et al. (2018) established the fact that it remains to see what actual integrated STEM education looks like in classrooms (Dare et al., 2018).

2.9. Summary

Based on accounts of the research field of integrated STEM education, I have described integrated STEM education as an educational phenomenon or movement permeated by many different agendas, rather than as one single educational entity we can agree on. The following is a summary of my take on integrated STEM, as I use it in this study.

As an educational approach, integrated STEM opposes ‘traditional’ ways of teaching such as focusing on acquiring subject content in teacher-led learning processes in a mono-disciplinary curriculum. Instead, it focuses on utilizing relevant aspects of science, technology, engineering and mathematics through problem solving of real-world challenges. This can provide students with meaningful, real-world learning experiences that enable them to understand how the STEM disciplines are interrelated to support students’ development of disciplinary competences as well as 21st century skills, and thereby achieve STEM literacy.

However, the literature of integrated STEM education points to various concerns regarding implementation too. These relate to the epistemological practices of the STEM disciplines, teacher skills and attitudes, and existing school practices that can either prevent or support teachers applying integrated STEM approaches in classrooms.

These concerns might also explain why we are yet to see wide-scale implementation of integrated STEM education in Danish comprehensive schools.

Having described my theoretical starting point, I will now continue to explain my theoretical framework and approach.

3. Theoretical framework

The reason why I have chosen to apply activity systems analysis (Engeström, 1987) in this thesis is because I needed a tool enabling me to understand why implementing integrated STEM in schools was related to so many challenges. As a theoretical and analytical approach, activity systems analysis provides a tool to understand and describe the interactions between individuals' activities in their relevant contexts, and is particularly helpful in identifying organizational changes and systemic contradictions shaping developments (Yamagata-Lynch, 2010; Jonassen & Rohrer-Murphy, 1999).

In this study, I this tool to analyse specific implementations of the integrated STEM programme, the Science Marathon, as an activity taking place in school settings. Centring the analysis on the teachers involved in Science Marathon, this enabled an exploration of the inherent difficulties of adopting these approaches from a teacher perspective.

Activity systems analysis therefore provided me with tools to analyse barriers related to implementing integrated STEM approaches as manifestations of systemic contradictions.

Such systemic contradiction are not necessarily irresolvable, and may indeed even be productive, because they represent a potential for change and development. Accordingly, I have applied activity systems analysis to describe how teachers in the process of conducting Science Marathon interacted with their activity settings, and how systemic contradictions influenced the activity (Yamagata-Lynch, 2010). This perspective is particularly relevant for paper 2 (Sølberg & Waaddegaard, 2022) and paper 3 (Waaddegaard & Sølberg, submitted), where it is unfolded in more detail. However, the activity systems approach has been central from an early stage of this thesis work.

Before I describe how I have applied activity systems analysis, it is necessary first to explain the basic assumptions underpinning activity systems analysis. Thus, I present a brief introduction to cultural-historical activity theory (hereinafter referred to as activity theory) focusing on the significant contributions of Lev Vygotsky's concept of a complex mediated act, and Alexi Leotiev's concept of collective activity. Finally, I introduce Yrjö Engeström's conceptual model of activity systems as an analytical tool, and account for how I have applied this model in my thesis.

3.1. Activity theory

The development of activity theory encompasses the work of many different scholars and has been applied to analysing various educational and corporate settings, as well as practical problem solving (Yamagata-Lynch, 2010). It dates back to the 1920s Russian scholars, where psychologist Lev Vygotsky is regarded as the founder of the theory and represents the first generation of activity theory (Engeström, 2001). I provide a brief overview of the succession of activity theory contributions as a necessary background to understanding the implications of how I have applied activity theory in this thesis.

Among Vygotsky's main contributions was the concept of a complex mediated act. Vygotsky developed this concept as a response to behaviourism, which was the most influential psychology of the time. In behaviourism, human mental processes are regarded as a simple stimulus and response process depicted as an S→R chain. This behaviourist understanding implies that the individual merely passively reacts to external environmentally inflicted stimuli (Engeström, 1987, pp. 77-78).

Vygotsky spoke against this predominant understanding of psychology by inserting artefacts into the equation. He thereby claimed that human consciousness developed in the process of interacting with artefacts (Yamagata-Lynch, 2010, pp. 15- 16), which are understood as either physical tools or mental signs (Engeström, 1987; Cole & Engeström, 1993). This had immense implications. When artefacts become integral parts of the process of human actions, the individual can no longer be understood as a decontextualized unit merely reacting to stimuli (Engeström, 2015, p. xiv). Instead, the physical tools and mental signs become means for humans to control their behavioural processes and master the environment (Engeström, 1987, p. 78).

At the same time, artefacts are produced and transmitted by people in the present and in the past, which means they are regarded as culturally produced artefacts carrying accumulated knowledge from prior generations (Cole & Engeström, 1993). Accordingly, when the individual interacts with artefacts, understood as using, producing, and exchanging artefacts, he/she actively takes part in culture. In other words, individuals actively make sense of the world by interacting with it. This understanding is connected to a dialectic materialist view (Jonassen & Rohrer-Murphy, 1999) where the individual's consciousness and culture are dynamically interrelated through the means of artefacts:

> "The individual could no longer be understood without his or her cultural means; and the society could no longer be understood without the agency of individuals who use and produce artifacts" (Engeström, 1987, p. 5).

So, human activity can only be understood in the cultural and historical context of which they are part (Engeström, 2015), and the use of artefacts ensures the continuity of human culture and the preservation of the past and the present (McDonald et al., 2005, p. 114).

In the Science Marathon activity, the main tool mediating the activity was an engineering design process model. This specific tool proved central for the teachers' interpretations of what it meant to teach integrated STEM in this particular context. At school (S4), one teacher instead chose a specific scientific enquiry-based model from her day-to-day teaching to mediate the activity. This meant that she did not interpret the Science Marathon activity as an integrated STEM approach, but rather as an approach to science learning. The interaction with these different artefacts in Science Marathon demonstrates that they shaped how the teachers made sense of the activity.

Alexi Leontiev, a former student and colleague of Vygotsky, continued to develop activity theory, and his work represents the second generation of activity theory (Engeström, 2001). Where Vygotsky's unit of analysis was limited to focus on the mediated complex act of the individual, Leontiev expanded the scope by focusing on collective activity (Engeström, 2001). In other words, he "turned focus on complex interrelations between the individual subject and his or her community" (Engeström, 1987, p. 5). According to Leontiev, a series of individual mediated actions in pursuit of the same collective motive constituted human activity (Yamagata-Lynch, 2010). From this perspective, it made no sense to consider individual actions without considering the overall historically evolved collective activity (Engeström, 2015). Thus, the unit of analysis shifted from a tool-mediated action to a collective activity. Accordingly, Leontiev contributed to activity theory by providing a clear distinction between goal-directed individual actions, and object-oriented collective activity (Engeström, 2001; Yamagata-Lynch, 2010). This contribution encompassed an understanding that the concept of activity is object-oriented, understood as a collective motive:

> "What distinguishes one activity from another is its object. According to Leont'ev, the object of an activity is its true motive. Thus the concept of activity is necessarily connected with the concept of motive. Under the conditions of division of labor, the individual participates in activities mostly without being fully conscious of their objects and motives. The total activity seems to control the individual, instead of the individual's controlling the activity" (Engeström, 2015, p. 54)

There are different understandings of the object, due to confusions when translating the term object from Russian to English (Kaptelinin, 2005). Therefore, I refer to the object of activity as the reasons why individuals participate in an activity, driven by their individual goals and collective motives (Yamagata-Lynch, 2010). In my research, I have defined the collective object of activity as implementing integrated STEM in comprehensive schools. I use the Science Marathon activity to demonstrate how this specific object is to be accomplished within four school settings. Within the Science Marathon activity, the teachers perform individual goal oriented actions. For example, they attend meetings to achieve agreement on how to organize the programme, they plan the programme to achieve a coherent lesson plan, they read the teacher guidelines in order to be prepared etc. While the teachers achieve these immediate goals, they are all oriented towards the object of conducting the Science Marathon.

3.2. Activity systems analysis

Yrjö Engeström (1987; 2015) merged Vygotsky's and Leontiev's perspectives of activity theory into a unified generic model (Figure 1), which is the tool often used in activity systems analysis and has been applied to this study.

Activity systems analysis is an approach to describing the "co-evolutionary interaction between individuals or groups of individuals and the environment, and how they affect one another" (Yamagata-Lynch, 2010, p. 22). The unit of analysis is the object-oriented activity (Engeström, 2015).

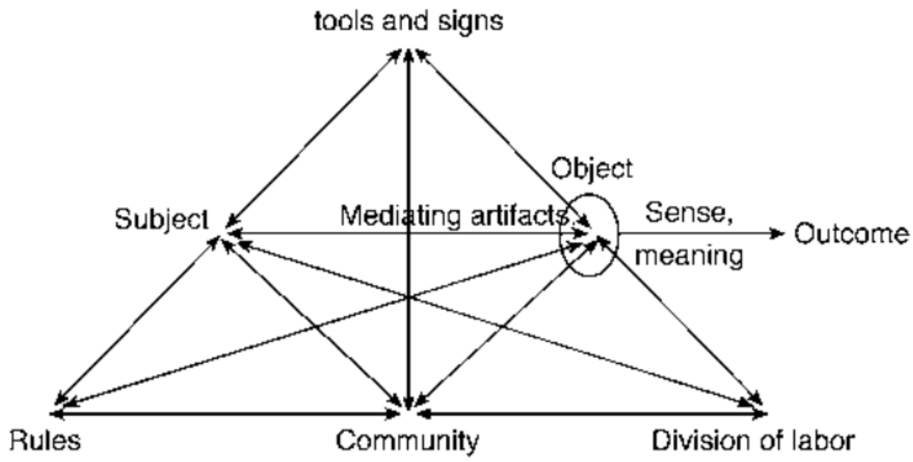

Figure 1: The structure of a human activity (adopted from Engeström, 1987)

Engeström's (1987; 2015) activity systems model integrates the concept of the complex mediated act (the top of the triangle in Figure 1) with collective activity (the bottom of the triangle in Figure 1). The primary focus in activity systems analysis is the top of the triangle, because it represents the production of an object, which is a physical or mental product being sought and represents the intentions motivating the activity. This object can be anything, as long as it can be acted on and transformed into an outcome by the subject (Jonassen & Rohrer-Murphy, 1999, pp. 62-65). Thus, the object is what defines and gives an activity direction as a collective motive. It both appears as a generalized and a specific object. The generalized object refers to the historically evolving activity system connected to sense-making on a societal level. Whereas the specific object refers to how the object appears to the subject at a particular moment in time and space and is connected to personal sense-making (Engeström & Sannino, 2021, pp. 8-9). In my research, I distinguish between a generalized object of implementing integrated STEM in comprehensive schools as a historically evolving activity, and specific objects of teachers carrying out Science Marathon within four different school settings.

The object is regarded as a space for negotiations, sense making and interpretations, and is a problem space with an always-existing possibility of transformation (Sannino & Engeström, 2018). Thus, the object is rarely in a state of stagnation. In my research, I consider the object being a site for negotiations and transformations as particularly relevant. In paper 1 (Sølberg & Waaddegaard, 2019), I have tried to demonstrate the many different interpretations of what integrated STEM in schools encompasses, and what goals to achieve. The lack of consensus as to what constitutes integrated STEM in schools, as demonstrated in section chapter 2., demonstrates clearly that this object-oriented activity is in a continuous process of negotiation and transformation.

Through mediation, the object is changed into an outcome, which is the result of an activity. This outcome can potentially be a transformation into a new artefact to be used in other activities. In my research, the outcome of the Science Marathon activity was the specific completion of Science Marathon at each of the involved schools, with a focus on the significance it had for the involved participants.

The subject in the activity system refers to the individual, or group of individuals, whose perspective is in focus in the analysis (Engeström & Sannino, 2021). In my research, the subject of the activity is represented by the groups of teachers carrying out Science Marathon at the four schools. I regard their behaviours as an entryway to analysing the activity (Yamagata-Lynch, 2010). The subject uses artefacts to transform the object into a desirable outcome (Jonassen & Rohrer-Murphy, 1999). By using a culture-specific tool both transform the activity and the tool in a dialectic interplay. This also suggests that the value of a cultural tool can change over time, and it can be replaced, innovated or discarded across activities (Yamagata-Lynch, 2010, p. 22).

In my research, the engineering design process model applied in Science Marathon was the most central tool mediating the activity, and regarded as a new tool adopted in the school settings, since none of the participating teachers were familiar with it before planning for Science

Marathon. In addition to this tool, the teachers at each school chose to apply other cultural tools, which were already an established part of the existing school cultures. For example, at one school, the teachers applied a poster depicting different smiley faces (Happy, angry, sad etc.) to mediate the emotional processes they expected their students would encounter. How the teachers interacted with these different cultural tools shaped their interpretations of the object and ultimately the outcome of their activity.

Rules, community, and division of labour refer to the collective aspects of mediated activity. The community refers to all the individuals who share the same object. The subject is part of this community as long as he/she participates in the activity (Yamagata-Lynch, 2010). Individuals participate in many activities, and therefore identify with many different social groups. This makes it an analytical question whether a given individual is part of the community in a given chosen context. In my research, besides the group of teachers carrying out Science Marathon, I identified that other community members participating in and influencing the activity at each school consisted of the school principal, the science coordinator, teacher colleagues and students.

Because members of a community share activity, it always consists of multiple perspectives, traditions, interests, and negotiations (Engeström, 2001). Rules and regulations mediate the relationship between the subject and the community. They can both be implicit or explicit norms, and sanctions that mediate what is regarded as correct procedures and interactions in the community (Cole & Engeström, 1993). These rules can be constraining or liberating for the subject (Yamagata-Lynch, 2010). I analysed which rules either constrained or supported the Science Marathon activities at each schools. Common for each school was the fact that the science curriculum influenced all activity systems and acted as a rule. There were also local rules that only applied within each school settings. These rules related to local norms and values. For example, at one school, the norm was to teach project and problem based, which acted as a supporting rule in the Science Marathon activity.

Based on the different formal and informal skills, members of the community can negotiate different roles and be assigned different tasks in the activity, which define the division of labour (Jonassen & Rohrer-Murphy, 1999). Thus, the division of labour refers to how the tasks in the community are divided among its members. This implies that the members of the community continually negotiate the distribution of power, tasks and responsibilities (Cole & Engeström, 1993). In my study, it varied across schools how the division of labour in Science Marathon was organized. For example, at some of the schools, Science Marathon was carried out by teacher teams, whereas it was carried out by individual teachers at other schools.

All these components mediated the interactions between the subject and object, and influenced the outcome of Science Marathon.

3.3. Five principles guiding the analysis of activity systems

Engeström (2001) described five principles that are important to consider when conducting activity systems analysis. These principles are related to the unit of analysis, multi-voiced activities, historicity, systemic contradictions and expansive learning. I describe and explain how these principles have been applied in this thesis.

According to Engeström (2001), the unit of the analysis is the object-oriented activity that must be regarded in its network relationship to other activity systems. In my thesis, I have considered the unit of analysis as conducting Science Marathon at each of the four schools, representing implementing integrated STEM in schools. I was particularly interested in how this activity was influenced by other school-related activities, such as other teaching and assessment practices taking place within the same school settings as Science Marathon. I have accounted for this in paper 2 (Sølberg & Waaddegaard, 2022) and paper 3 (Waaddegaard & Sølberg, submitted). Analysing these network relationships was crucial because it enabled me to identify systemic contradictions within and between the Science Marathon activity and other school activities.

Engeström (201) describes his second principle as activity systems being multi-voiced. It means that there are always multiple points of view and interests at stake in activity systems. He adds that this in itself can be a source of potential tension and innovation, because members of the community can demand different actions. I considered this principle in my thesis as a defining feature of the generalized object of implementing integrated STEM in schools. In chapter 2, I have accounted for some of these different perspectives and interests at stake in integrated STEM education, which illustrates that the activity is rather unstable and in a constant process of evolving through the continuous resolution of the many conflicts involved.

Engeström's (2001) third principle is historicity. Over time, activity systems evolve by transforming and developing. This means that some practices within activity systems can be institutionalized and constituted as cultural practices over time. These cultural practices tend to reproduce similar actions and outcomes repeatedly (Cole & Engeström, 1993). This demonstrates that in activity systems, history is always present in layers of earlier forms of activities, inscribed in artefacts and rules and as ways of thinking (Engeström & Sannino, 2021; Sannino & Engeström, 2018). Thus, demonstrating that "layers of history actively [influence] the present day actions of the practitioners" (Engeström & Sannino, 2021, p. 6). Accordingly, it is necessary to study local history, objects, and tools of the activity system to understand how it was shaped (Engeström, 2001; Cole & Engeström, 1993). If the history of the activity is ignored, individual actions may be wrongly interpreted as arbitrary, because the underlying reasons are missing (Engeström & Sannino 2021; Sannino & Engeström, 2018). I have applied this principle in my thesis, as I was particularly interested in how the teachers described the existing school practices as a foundation for understanding the tensions that mediated the activity of conducting Science Marathon.

According to Engeström (2001), the fourth principle to consider in activity systems analysis is contradictions. Systemic contradictions are historically accumulated structural tensions within and between activity systems (Engeström, 2001). However, we do not have direct access to them. Hence, we must recognize them analytically as manifestations of tensions between different components of the activity system (Sannino & Engeström, 2018). While a systemic contradiction cannot be reduced to a subjective experience of tension, the subjective experience can be a manifestation of an underlying systemic tension (Yamagata-Lynch, 2010). A contradiction emerges when an activity system adopts a new tool or a new rule from outside that collides with the old existing ways of thinking and doing (Engeström, 2001). Contradictions are not necessarily regarded negatively as problems, but as sources of transformation, and they are the reasons why an activity system seldom is in a state of equilibrium (Cole & Engeström, 1993).

This fourth principle is central throughout my thesis, as it provided a foundational tool for me to understand the potential barriers impeding teachers from applying integrated STEM approaches, as manifestations of systemic contradictions.

Engeström's (2001) fifth principle is the possibility of expansive learning. This principle is related to the systemic contradictions regarded as the driving force in the transformation and development of activity systems. For expansive learning to occur, individuals within the activity system start to think critically about the established norms and conventions as a response to the tensions they experience. They may then begin to deviate from the established rules through their actions. Over time, this can develop into a collective transformation process of the entire activity system. When this happens, the object of activity has expanded to adjust to new practices, and expansive learning has been accomplished (Engeström, 2001; 2017). Thus, learning is understood as the process of collective transformation and development. In this process, the subject is regarded as a potential change agent whose actions can initiate the transformation cycle. This form of agency can emerge when humans are able to transform their circumstances by breaking free of a conflicting situation (Engeström, 2017; Sannino & Engeström, 2018, p. 50).

The concept of expansive learning helps to understand how new forms of activities develop over time, by looking at how the object is transformed and how new kinds of knowledge and practices emerge. In this thesis, I have considered expansive learning as a possibility at each school investigated. However, as expansive learning cycles happen over long periods of time (possibly years), it was beyond the reach of this thesis to capture this transformation cycle as a whole.

3.4. Activity systems analysis applied

In this last subsection of the chapter, I will provide a depiction of the activity system of conducting Science Marathon. I will also provide the last details about my approach to activity systems analysis.

In my study, the unit of analysis as an object-oriented activity was to implement integrated STEM education in schools. I considered this unit a generalized object (Sannino & Engeström, 2018), encompassing an analytically insurmountable large community, and so taking place in an undefined time and place at the societal level. Paper 1 (Sølberg & Waaddegaard, 2019) focuses on the generalized object, by describing what characterize teachers' and students' integrated STEM practices across schools, grade levels and initiatives, to provide a more broad and encompassing perspective of the object. To understand this activity as a specific object (Sannino & Engeström, 2018), I selected Science Marathon as the unit of analysis. In section 4.2., I account for the reasons why I selected Science Marathon as a case to study. I regarded the four selected schools to encompass the 'activity settings', which are the social context anchoring the activity and other activities with similar objects (Yamagata-Lynch, 2010, p. 24). It was obvious to choose the group of teachers in each school responsible of conducting Science Marathon as the subject of the activity system – thereby enabling me to identify the concrete activity systems in focus, illustrated in Figure 2.

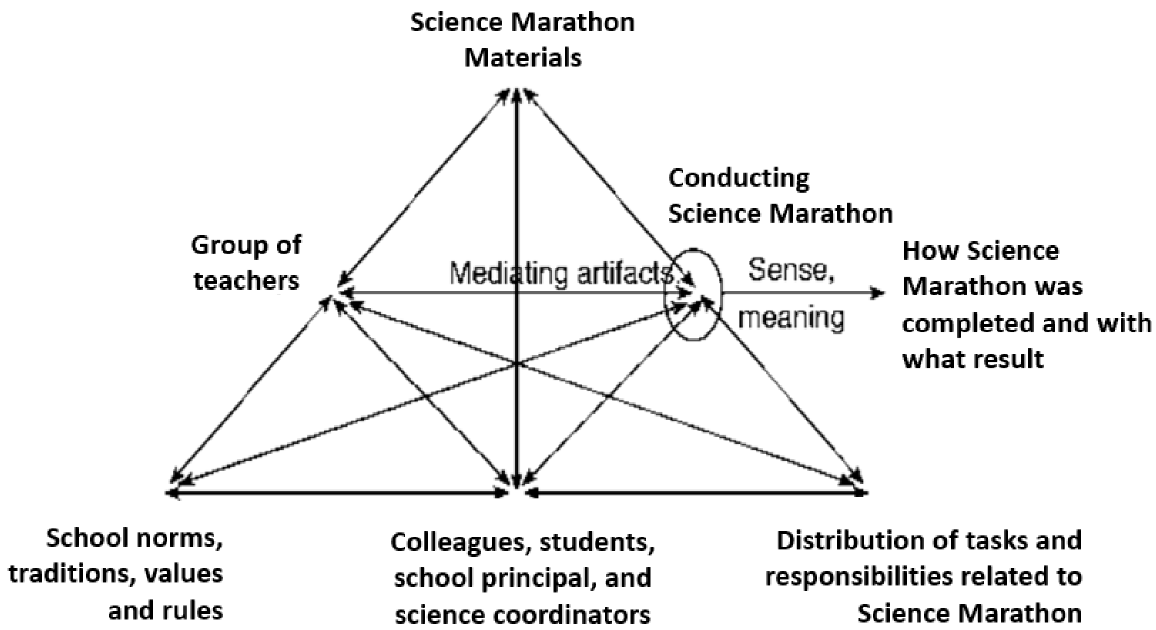

Figure 2: The activity system related to conducting Science Marathon at each of the four schools derived from Engeström's model of the structure of a human activity (1987).

Having described activity theory and explained how I have applied activity systems analysis in my research, I will now proceed to describe my methodology.

4. Methodology

In the next sections, I describe my methodological design and the reasons why this particular design would enable me to answer my research questions and problem statement.
First, I introduce my use of a case study as a qualitative methodology suitable as an overall research design. Second, I describe the selected case of Science Marathon. I account for how I regard this educational programme to be an illustrative case of integrated STEM education in Danish comprehensive schools. Third, I account for my strategy and criteria for selecting schools. Fourth, I describe the research methods applied to collect relevant data, and the analytical strategy I have used to analyse my data for the purpose of this study. Fifth, I account for the ethical considerations that apply to this study. Finally, I reflect on my research design.

4.1. Case study

I have chosen a case study as my methodology, because I regard this type of research design as particularly suitable for two main reasons. First, the case study is well suited for addressing my overall research problem. Merriam (2007) describes that case studies can be used if the researcher is interested in exploring a process, such as implementation of a programme, whereas Yin (1981, p. 100) describes case studies as suitable when you want to ask "'how' and 'what' questions". My research question addresses both these criteria, since I am interested in what systemic contradictions mediated the implementation of integrated STEM education in Danish comprehensive schools.

Second, my theoretical approach of activity systems analysis is compatible with case studies, because both activity systems and case studies involve investigations of self-sustaining systems that are difficult to remove from their context. Case studies as a methodology are an examination of a bounded system, which can give activity systems analysis an organizing framework to focus on (Yamagata-Lynch, 2010). In other words, the selected case becomes the unit of analysis in activity systems analysis.

There are multiple definitions for and approaches to case studies (Yazan, 2015). For example, Yin (1981) defines case studies as needed, when "an empirical inquiry must examine a contemporary phenomenon in its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 1981, p. 98).

Even though I apply the notion of case studies as being suitable for studying a phenomenon taking place in a real-life context, I do not subscribe to Yin's (1981) positivistic view, which is evident in his orientation towards objectivity, validity and generalizability (Yazan, 2015, p. 136). Besides, he does not want to be associated with qualitative research (Henriksen, 2003, p. 14).

Merriam (2007; 2002) understands case studies as based on qualitative research methods, which resonated well with the nature of my research question. Moreover, the constructivist philosophical assumptions underpinning Merriam's approach to case studies (Yazan, 2015) also corresponded to my theoretical framework of activity theory. From both perspectives, focus is on how people make sense of the world. I therefore chose to apply Merriam's (2007) understanding of a case study, characterized as a delimited object of study understood as a 'bounded system' (Merriam, 2007, p. 27). This means that she refers to the case as, for example, an entity, a unit or a programme, demarcated by boundaries.

Corresponding to this understanding, I selected the educational programme Science Marathon as a bounded system to study. I selected Science Marathon as a case because it represented one way to explore the overall phenomenon of implementing integrated STEM education in school (which I describe in detail in section 4.2). Studying how groups of teachers at four different schools conducted the Science Marathon programme in their teaching activities enabled me to produce in-depth, rich, context-dependent knowledge, which proved relevant for revealing important aspects of the more general phenomenon (Merriam, 2017) of implementing integrated STEM in comprehensive schools. Thus, the general phenomenon corresponds to the understanding of the generalised object from the perspective of activity theory.

As such, Science Marathon was a bounded system occurring in a bounded context, limited in time and space, constituting the case as an entity (Flyvbjerg, 2011). More precisely, it was limited to the particular people involved in the Science Marathon activities at each school, to the number of hours they spent on these activities, and the tools they used to mediate the activities. The drawing of these case boundaries helped me to define the context of the case, as the particular settings of the four schools, which allowed me to focus on the relationship between the case and the environment (Flyvbjerg, 2011).

From an activity theoretical perspective, the bounded case at each school studied constituted the activity systems, whereas the particular settings of the four schools constituted the activity settings, as the site where the object-oriented activities took place (Yamagata-Lynch, 2014).

Choosing a case study as the methodology fitted well with my explorative approach, since case studies can bring forth discoveries of new meaning and explanations (Merriam, 2007). In fact, Flyvbjerg (2011) asserted that case studies should not be applied as a methodology to prove anything, but to learn something about human affairs.

However, by choosing case studies as a methodology it is possible to question the representability the findings. In other words, do four case schools have any descriptive power regarding implementation of integrated STEM in comprehensive schools? According to Flyvbjerg (2011, p. 305) we have a tendency to overvalue formal generalization as a source of scientific development, whereas we underestimate the case study's force of example and transferability (Flyvbjerg, 2011, p. 305). In fact, case studies are central to the development of new theory because it is an ideal approach to either falsify or prove a hypothesis pointing to development of new concepts and explanations. I chose Science Marathon because to me it represented 'a critical case' (Flyvbjerg, 2011, p. 307). This meant that I regarded it as having a strategic important relation to the general phenomenon of implementing integrated STEM. In other words, Science Marathon provided teachers with relevant teaching materials, an engineering design approach, elaborated student challenges, teacher guidance, introduction courses, and even a 'hotline' to call in with various types of questions regarding the programme. This meant that Science Marathon provided teachers with support and great conditions for conducting integrated STEM approaches in their teaching. If I still identified tensions to conducting integrated STEM approaches within these settings, it would be most likely that other attempts at implementing integrated STEM, without support, would include similar tensions. From this strategic choice, I was able to make a logical deduction that if there are tensions involved in conducting Science Marathon, then this would apply to all other cases of implementing integrated STEM.

4.2. Selected programme – Science Marathon

I selected the Danish educational programme called Science Marathon as a case for studying systemic contradictions mediating the implementation of integrated STEM approaches in comprehensive schools in Denmark.

Science Marathon is an educational programme organized by the House of Natural Sciences, funded by Novo Nordisk Fonden, Villum Fonden, Grundfos, and the Ministry of Children and Education.

The programme is based on nature/technology, mathematics, and craft and design subjects for students at grade levels five and six (aged 11 and 12 years). It gives teachers and students experiences with enquiry-based and hands-on teaching activities, to enhance student interest and motivation for the science disciplines (Naturvidenskabernes Hus, n.d., a).

The structure of the Science Marathon programme follows the school year. At the beginning of the school year, six student tasks are announced, and in the second half of the school year, the actual Science Marathon teaching activities are conducted at each schools. The programme ends with a competition, where school classes from the same municipality compete against each other.

The student tasks in Science Marathon are about solving practical problems. The tasks provide students with grade level appropriate disciplinary challenges, and can be solved in more than one way. The student tasks are solved by applying an engineering design process. Accordingly, students must engage in an engineering design process based on iterative sub-processes of understanding a problem, making enquiries, creating ideas, planning work, building a construction, testing the construction, and improving on it.

The particular engineering design process model applied in Science Marathon is developed by the nationwide school programme ‘Engineering in the School’. It is a design based approach to working with authentic problems, through enquiry-based and hands-on learning, by constructing prototypes to strengthening students’ science competences and interest in STEM disciplines (Engineer the Future, n.d.).

In 2019, I collected data from the four schools engaged in the Science Marathon programme. This year there were eight student challenges in Science Marathon. First, each challenge was introduced in a narrative about the ‘Green Ville’ village, where the people who lived there needed help to make the village more eco-friendly and sustainable. The student tasks followed a similar structure, including a knowledge task, a construction task, and a modelling task. The construction task included building a prototype as a practical solution to a problem, and the modelling task included activities like making a stop-motion movie (Naturfagsmaraton, 2019).

Teachers can participate in an introduction course they can attend either online or physically as preparation for the programme. At the course, the teachers are introduced to the engineering design process model applied as instructional approach, and receive guidance in how to organize and prepare for Science Marathon in their teaching activities, such as what materials to gather in advance.

It is recommended that students are organized in small groups, and the instruction is based on student-centred pedagogies, to provide opportunities for the students to work independently and make decisions. The teacher is recommended to take the role of a supervisor, guiding students to find their own solutions (Naturfagsmaraton, 2019).

The expected number of lessons spent on Science Marathon is between 12 and 20. The teachers can decide for themselves how they want to organize these lessons as teaching activities. It is therefore possible to organize Science Marathon either in single lessons or as a project.

In the final competition, students and teachers from the same municipality meet to compete, class against class. The student groups present their solutions to the student challenges in front of a panel of judges comprising three teachers. In the presentation, students can explain why their prototype is a good solution, what they have learnt in the process and if they made any mistakes during the process (Naturfagsmaraton, 2019). The judges assess the students' presentations and give them points. The class with the most points wins the Science Marathon competition and receives a winner's cup.

4.2.1. Is Science Marathon a representative case for integrated STEM approaches?

The name 'Science Marathon' indicates that science is the predominant discipline. Just as the description above shows that science is the predominant focus (to arouse interest in science). Whether the organizers of Science Marathon would call it an integrated STEM or a science programme, I do not know. This makes one question as to why Science Marathon has been selected as a critical case on how to conduct integrated STEM approaches in comprehensive schools.

The justification for defining Science Marathon as a critical case of how integrated STEM approaches can be implemented in Danish schools is based on three arguments.

First, Science Marathon integrates disciplinary aspects from mathematics, engineering and craft and design in nature/technology. This corresponds to Sanders' (2009) definition of integrated STEM as including teaching and learning between any two or more of the STEM subject areas (Sanders, 2009, p. 21).

Second, the approaches applied in Science Marathon resonate with integrated STEM approaches based on student-centred pedagogies, design-based learning, problem-centred learning, enquiry-based learning, and cooperative learning (Thibaut et al., 2018).

Third, even though the main aim in Science Marathon is to develop student interest in science, this does not exclude it from being integrated STEM. As described in section 2.4., STEM education is often associated with achieving science related goals (English, 2017). Just as Danish STEM strategies are often implemented with a political aim to improve science education. In Science Marathon, the engineering design process model provides students with an engaging context to achieve science based learning goals.

Having described the Science Marathon programme and accounted for the reasons why I have chosen this programme to illustrate integrated STEM, I will continue to describe the selected schools and groups of teachers I followed while conducting the Science Marathon in their teaching activities.

4.3. Selected schools

When selecting case schools, I applied what Flyvbjerg (2011) described as a strategy of maximum variations. This strategy involved selecting schools that varied on one or two dimensions (Flyvbjerg, 2011). In this study, the case schools varied on the dimension of organizing the Science Marathon programme. This enabled me to obtain valuable information about whether variance in ways of organizing Science Marathon proved significant about how systemic contradictions influenced the outcome of activity.

I will now provide a brief overview of how the four schools varied in their organization of Science Marathon. The number associated with each school has been assigned randomly and has no further significance.

School 1 (S1): Eight teachers from the middle school teacher team participated in Science Marathon with four classes (fifth and sixth grade students). The teachers covered various subjects such as science, mathematics, craft and design, music, Danish, and English. All teachers had participated in Science Marathon before (1-8 times). They organized it to be implemented over the course of a school week. During the activity, the teachers collaborated closely in shared teaching activities.

School 2 (S2): Three teachers (two of them from the same teacher team and one ‘borrowed’ from another team) participated in Science Marathon with four classes (sixth grade students). The teachers covered science, mathematics, and craft and design. All teachers had participated in Science Marathon before (2-3 times). They organized it in their separate classes in the context of the nature/technology subject, with a minimum of collaboration. They accomplished Science Marathon during approx. 12 nature/technology lessons and two craft and design lessons over the course of two months.

School 3 (S3): Five teachers from the middle school team participated in Science Marathon with eight classes (fifth and sixth grade students). They organized it as two separate activities following the grade levels. The teachers covered science, mathematics, Danish, craft and design, and music. One of the teachers had participated in Science Marathon over 10 times, and another had never participated before. During the Science Marathon activity, the teachers collaborated closely and shared practices. They accomplished Science Marathon during four project days over the course of a month.

School 4 (S4): Two teachers participated in Science Marathon with two classes (fifth grade students). The teachers covered nature/technology and Danish. None of the teachers had participated in Science Marathon before. The teachers had planned the activity together but taught it separately. They accomplished Science Marathon during 10 lessons over the course of two months.

Having described the selected program and schools, I will continue to account for the research methods applied in this study.

4.4. Participant observations

In my research, I have applied participant observations as a qualitative research method that allowed me to collect data in naturalistic settings (DeWalt & DeWalt, 2011). This means I have collected data from interacting with and observing the group of teachers conducting the Science Marathon programme in their local school settings. Participant observations is a particularly suitable method to describe and understand local, situated, and social aspects in people's everyday lives (Szulevitz, 2020, p. 102). By applying this method, I developed an understanding of how the implementation of integrated STEM in schools could unfold, situated in the specific contexts of four schools engaged in the Science Marathon activity. This understanding developed as I followed the teachers engaged in Science Marathon at each school interacting with their social environments.

Participant observation is a method to collect cultural knowledge about the local values, rules and ways of thinking and doing (DeWalt & DeWalt, 2011). It is a method concerned with how people make sense of the world by interpreting the meaning assigned to their actions, which are mediated by their culture. We use our cultural knowledge to interpret our experiences (Spradley, 1980). To me, this meant that I needed to get to know the cultural norms, artefacts and behaviours that shaped these teachers' actions, in order to understand how they made sense of Science Marathon as a teaching activity. By applying participant observations, I was able to take part in the teachers' daily life while conducting Science Marathon, thereby gaining information about the cultural practices that characterized the observed community (Szulevitz, 2020, p. 103) and mediated the teachers' actions.

By observing the teachers in real-life situations, engaged in goal-directed actions and object-oriented activities (Yamagata-Lynch, 2014), I was able to collect valuable knowledge to inform my activity systems analysis. While I conducted participant observations in the field, I especially focused on the physical surroundings, who participated in what activities, what the purpose of these activities were, and what artefacts were used to mediate them. From my participant observations, I learned about the teachers' daily life and the cultural practices that mediated how they made sense of the Science Marathon activity.

4.4.1. Entering the field

Having defined my research problem and selected the Science Marathon programme as a case illustrating one way to conduct integrated STEM approaches in schools, I needed access to schools participating in the programme. First, I established a collaboration with the House of Natural Sciences (‘Naturvidenskabernes Hus’), to study Science Marathon as a case. They introduced me to the Science Marathon programme, allowed me to participate in introduction courses and gave me access to relevant documents, thereby initiating my introduction to the relevant community (science teachers going to participate in the programme). They also advised me to contact the science coordinators from different municipalities as a gateway to entering this community of science teachers (DeWalt & DeWalt, 2011) as they are important representatives of this community within their municipalities and have a large network of science teachers. They ended up being the key to gaining entrance to the field (the four schools). Some of the science coordinators put me in contact with science teachers they knew were going to participate in Science Marathon, while others offered that I could follow them. This was possible because, besides being employed as science coordinators, they were employed as science teachers at local schools and were going to participate in Science Marathon.

Following this approach, I established contact with four teachers at four different schools, who agreed to collaborate with me by being my informants. These four teachers were particularly important for me because they introduced me to the other teachers going to participate in Science Marathon, thereby giving me access to the relevant community. In other words, they acted as my ‘gatekeepers’ (Kristensen & Krogstrup, 1999, p. 139) by vouching for my presence during activities such as team meetings, planning the programme and teaching the programme. By being open about the purpose of my research, we established a respectful relationship based on cooperation. They provided me with information, while I listened carefully to what they had to say (DeWalt & DeWalt, 2011) giving them an opportunity to tell their story.

4.4.2. My role as participant observer

A researcher’s participation in the studied field can range from non-participation to full participation, whereas I predominantly took the role as a moderate participant (DeWalt & DeWalt, 2011). I was present at all times in the activities, while still being identifiable as a researcher. I frequently interacted with both teachers and students through informal dialogues. However, I was also a newcomer to the field (Kristiansen & Krogstrup, 1999), and did not know the cultural language or behaviour appropriate in these settings, since I had no prior experience of what it was like to be a teacher in a comprehensive school. Neither did I have sufficient time to learn to embody this behaviour, enabling me to move from peripheral to full membership (DeWalt & DeWalt, 2011). Science Marathon only lasted for a short period and my participation was limited to activities that related to Science Marathon.

This had implications for the data I was able to collect, presenting both opportunities and challenges. Had I been able to participate more actively, I could have achieved a deeper level of understanding regarding the cultural knowledge and values mediating the teachers' actions. Instead, I participated as a 'cultural baby' (DeWalt & DeWalt, 2011, p. 44), allowing me to ask many naïve questions that would have been considered obvious as an insider. From these questions, I got some of the most interesting information that challenged my own assumptions about how and why the teachers they did as they did.

4.4.3. Preparation and field notes

Since I was not able to stay for extended periods in each school, I had prepared my entrance in the field (Schulevitz, 2020). I had prepared by defining my research question and my theoretical framework, which was helpful to direct my observations towards specific interactions. I did not use a structured observation protocol, but in my research design, I had written down focal points to pay attention to:

- What artefacts mediate the activity?
- What activities do the teachers encourage students to participate in?
- What is the criteria for successful participation in Science Marathon?
- What kind of knowledge do the teachers describe as relevant in Science Marathon?
- What are the relationships between the teachers?
- What language do the teachers use to describe Science Marathon, as well as their regular teaching activities?
- What values permeate the teachers' actions?
- Are there any obstacles impeding teachers from performing the activities?

I directed my attention towards such concrete interactions, to gain knowledge about how the teachers made sense of the Science Marathon activity. I recorded my participant observations in field-notes. I also audio-recorded some conversation and took pictures of the settings (of student solutions to tasks, classrooms, lab-rooms and tools used). I used citation marks when writing down in verbatim what the teachers said. These quotes documented the language of the field, which was different to the condensed summaries I otherwise wrote down (Spradley, 1980). For example, I quoted when the teachers from school (S1) referred to Science Marathon as the “science week” because it revealed an important aspect about the culture of that particular school shaping the Science Marathon activity.

Using a notebook, I described the observed events jotting down short sentences to aid my memory (DeWalt & DeWalt, 2011, p. 180), to the extent it was possible without making it socially awkward that I was observing what the participants did. I wanted to avoid them feeling uncomfortable, which could potentially change their behaviour (Kristensen & Krogstrup, 1999, p. 151).

When writing down field notes you create a bridge between observations and analysis (Spradley, 1980). It is a way to make sense of the observations, which means it is not an account of an objective reality but an account of my interpretation of the reality (Kristensen & Krogstrup, 1999, p. 153). This makes self-reflection crucial to identify potential bias (which I account for in section 4.7.). When I left the field, I wrote down extensive field notes while my memory was still fresh. I tried to make descriptive and detailed accounts of what happened, while avoiding interpreting the participants’ emotional motives.

In total, I conducted 125 hours of participant observations informing this research project.

4.5. Interviews

Besides participant observations, I also interviewed 14 teachers and three school principals in continuation of my observations. I chose to conduct semi-structured interviews, to get close to my informants’ subjective experiences (Tanggaard & Brinkmann, 2020) related to the Science Marathon activities, as a proxy for integrated STEM. From an activity theoretical perspective, I selected my interviewees based on their affiliations with the Science Marathon activities conducted at each school. Both teachers and school principals were members of the community that constituted the Science Marathon activities at each schools.

The teacher interviews were a means to identify the teachers’ subjective experiences (the subject), and their interpretation on the Science Marathon activity (the object). Although most teachers selected taught the nature/technology subject, I also selected teachers with different disciplinary backgrounds, because they represented a different perspective on the activity. In the interviews with the teachers, I focused on how they made sense of the Science Marathon activity in relation to their regular teaching activities.

I interviewed the school principals based on their different roles and perspectives on the Science Marathon activities. Here, I focused on how they made sense of Science Marathon in relation to other schools agendas.

I recruited my informants while in the field conducting participant observations. I simply asked them in person if I could interview them. If they agreed, we would set a time and place. All, except two interviews, were conducted at school sites in meeting rooms, teacher rooms or in the principals' offices. The last two interviews were conducted in a cafeteria and in a local science centre. The length of the interviews lasted from 30 minutes to 90 minutes, which depended on how talkative the interviewee was. The interviews happened in close proximity to the Science Marathon activities (still in the process of conducting the Science Marathon or within a few days after completion). This meant that the teachers' experiences with the Science Marathon were still relatively fresh in their memories. One interview was conducted about three weeks after Science Marathon had been completed at the school, which impacted the interview. The teacher I interviewed told me that in the meantime she had attended to so many other tasks that her memories from the Science Marathon activity had already faded.

The Science Marathon activities were conducted during the 2018/2019 school year, but at different times at each school during the second half of the school year. My research perspective accordingly developed from case school to case school, as I learned more about what was at stake for the teachers, which sharpened my focus during my interviews. I conducted the interviews in extension of my participant observations, which proved to be a good strategy, because I had already developed knowledge about specific tensions relevant in each setting. In the interviews, I used this knowledge to ask additional questions of relevance and I used the interviews to verify the knowledge from my observations (Yamagata-Lynch, 2010). For example:

> Researcher: "you and your colleagues said something like, 'you use a lot of time to cover the different subject areas in the curriculum and that it could impede problem-based approaches'. Would you say more about that?"
>
> Interviewee: "Yes and I still believe that. It is because if you want to immerse yourself in some of these areas then one or two weeks are not enough. Then the students need more time to work with it […]"

In this example, I referred back to a specific observed situation I had described in my field notes. The interviewee could verify the observation and elaborate on it.

I always staged the interview by briefing my interviewees (Kvale & Brinkmann, 2009) about the purpose of my research and by going over what topics that I wanted to discuss with them. Afterwards, I debriefed them, enabling the interviewee to express final thoughts.

I designed two semi-structured interview guides (one for teachers and one for school principals).

The interview-guide for the teachers covered the themes:

- Perspective on what is good nature/technology teaching and how to conduct it.
- Experiences with the Science Marathon, reasons for participating and the purpose of the activity.
- The desired learning outcome in the Science Marathon and if it has been achieved.
- Advantages and disadvantages of applying an engineering design process model compared to other approaches.
- The nature of teacher collaboration
- Supporting/impeding school structures

The interview guide for the school principals covered:

- School values and visions
- Project and problem based teaching and learning on the school agenda
- STEM initiatives
- Knowledge and involvement in the Science Marathon
- Teacher team organization

During the interviews, I would ask follow up questions by encouraging the interviewee to continue describing his experiences and attitudes towards the topics. I also used prompts such as prolonged pauses, encouraging nodding, and repeating of words. I sometimes used interpretative questions (Kvale & Brinkmann, 2009) to clarify that I understood the answer correctly. When I felt a topic had been covered sufficiently, I introduced a new topic.

I audio-recorded and transcribed all the interviews.

4.6. Analysing data

For the purpose of this study, I conducted a thematic analysis to organize and identifying patterns of data as overarching themes. I followed the six steps to analysis recommended by Braun and Clarke (2006, p. 87):

Familiarisation with data, 2) initial codes, 3) searching for themes, 4) reviewing themes, 5) defining themes, and 6) writing the report.

I will account for these steps chronologically, although it was in fact an iterative process, where I had to return to earlier steps several times.

I started familiarising myself with data from the moment I started to write down field notes. Here, I engaged in a preliminary analysis (Spradley, 1980). This was an iterative process of going back and forth between writing down field notes, reading the field notes, thinking about what it meant, writing analytical comments and returning to the field with new questions. By transcribing the audio-recorded interviews, I also got a better sense of my data that sharpened my understanding of what was at stake.

Next analytical step was to create initial codes. Using the software program Atlas.ti I made an open coding of the entire data corpus. I gave each code a name and described what constituted the individual codes. For example, I would name a code 'open-ended tasks' and describe this code as "teachers' descriptions of the Science Marathon characterized by open-ended tasks and opposed to 'teacher-defined tasks". This open coding process resulted in more than 100 codes. In this process, I went back and forth between merging codes that overlapped and creating new codes.

Next, I began to search for themes in my coded data. Braun and Clarke (2006) describe a theme as a patterned meaning in the data set. To find these patterns, I first attempted to bring order to data by drawing mind maps. In these mind maps, I would draw arrows between codes to illustrate their relations. Then I would write down how they were connected.

For example, I linked the code 'enquiry-based approach to science instruction' with 'engineering design process model'. Then I would describe this link, which in this case was that the teachers often compared them.

Based on the mind maps I returned to the software program Atlas.ti to construct the themes and to further elaborate what they meant. Due to the relatively large data-corpus, this was a difficult process. Braun and Clarke (2006) describe that it is the researcher's judgement of what determines a theme. However, at this point, I was only able to create links between the codes to make coherent patterns, but I still needed to interpret what these links meant.

This called for a review of my themes, which I did by comparing my initial themes with the STEM literature and my research question. Here, I shifted from an initial inductive coding to a deductive reviewing of themes. In this process, I needed to break down some of the initially created themes because I now interpreted them from the perspective of integrated STEM theory. This perspective made the process more focused enabling me to identify patterned meanings of the data. For example, I had constructed an initial theme related to teachers' disciplinary understandings. However, this theme was difficult to work with because it encompassed too many codes with too many potential interpretations. However, informed by the integrated STEM literature, I was able to make new connections and distinguish between patterns of STEM pedagogies and patterns of ‘traditional’ pedagogies’. This enabled me to connect 7 codes: ‘engineering design process’, ‘competences’, ‘learning from failure’, ‘open-ended tasks’, ‘inquiry-based approaches’, ‘facilitator of learning’, and ‘motivation to learn’ as a patterned theme about STEM-pedagogies. The connection between these codes constituted what the teachers interpreted as characterizing the pedagogies applied in the Science Marathon.

Having reviewed all my themes, I ended with the following six themes. Each theme, I regarded as relevant for answering my research question:

- Curriculum integration (the subjects emphasized as important in the Science Marathon).
- Perceived goals to achieve compared to regular teaching activities (teachers’ interpretations of disciplinary goals (competences as well as content) and 21st century skills as important).
- STEM-pedagogies (teachers’ interpretations of approaches characteristic for integrated STEM as relevant in teaching activities).
- Traditional pedagogies (Teachers’ interpretations of approaches characteristic for ‘traditional’ pedagogies as relevant/irrelevant in teaching activities).
- Teacher insecurities (teacher insecurities about their capacities to teach integrated STEM).
- Other school practices (how school practices such as teaching and assessment activities either impede or support teachers while conducting integrated STEM).

Having constructed my themes in meaningful patterns, I regarded them from the perspective of activity theory by asking questions relevant for an activity systems analysis. For example, I asked what activities these themes connected to; what systemic contradictions would bring tensions in the activities; what was the outcome of the activity; how different activities interacted with each other, and if all participants regarded the object the same ways, inspired by Yamagata-Lynch (2910, p. 75).

Finally, I wrote down the reports, which constitutes the papers of the thesis.

4.7. Ethical considerations

Qualitative research involves multiple ethical considerations from designing a study to reporting the results. “Ethics is about thinking through our relationships and our responsibilities” to our informants as well as to the broader public (Harper, 2014, pp. 91, 101). In qualitative research, these responsibilities are reinforced because we study people and their personal lives and experiences (Brinkmann, 20, p. 581). Ethical dilemmas can therefore emerge at any stage in the research process (Harper, 2014). In this chapter, I intend to describe my ethical considerations related to this research project.

First, it was important that I had the teachers' informed consent to participation before I started the research. Treating people with respect requires giving them opportunity to agree to participation according to (DeWalt and DeWalt, 2011; Kvale & Brinkmann, 2009). I prepared a consent form for the teachers to sign in agreement with the General Data Protection Regulation part 5 and 6 (Datatilsynet, 2017). By signing it, they agreed that they were informed about the research project. This included that they knew participation was voluntary, they had the right to opt out at any time, I guaranteed them anonymity, I was the only person having access to the data, and I would only use the data for the purpose of this research project.

However, as Harper (2014) put it, obtaining the formal paper with informed consent is not the same as our ethical engagement is over. It is even more important that we consistently commit to the 'spirit' of informed consent (Harper, 2014, p. 94). In other words, ethics is not only about complying with the ethical guidelines, it is also about personal virtues such as the ability to understand and respond to an ethical problem in the situation (Kvale & Brinkmann, 2009, p. 79). From this perspective, I considered it crucial to achieve transparency throughout the entire research process.

Accordingly, I arranged an introduction meeting at each schools to meet the teachers participating in Science Marathon to tell them about myself, and the research project. I did this to establish clear lines from the beginning of our collaboration, which is also part of forming respectful and effective field relations (DeWalt & DeWalt, 2011). At the introduction meetings, I received verbal permission from the entire community of teachers to access the field and follow them while conducting the Science Marathon.

Considering how I could contribute to the teachers' practices (Brinkmann, 2020) I could only offer an outsider perspective on their teaching practices by asking questions about their ways of doing and thinking, and listening to their stories (DeWalt & DeWalt, 2011). However, all teachers were content with this offer and some of them afterwards told me, they indeed had experienced my presence as a benefit.

There is always a potential risk of participating in research related to the possibility of discussing sensitive topics, failure to protect confidentiality or unanticipated results of publication (DeWalt & DeWalt, 2011, p. 233; Kvale & Brinkmann, 2009, p. 91). To avoid such risks I took measures to protect the teachers' anonymity and their confidentiality trusted on me. To my knowledge, I did not gather information that could have severe consequences for the informants. I made sure that all teachers' identities were anonymous by never writing down names. Instead, I came up with a system referring to each schools as a number, and the teachers were labelled with the number of the school followed by a letter: for example, school 1 with teacher 1a and 1b.

I briefed my interviewees before I started interviewing them by telling them about what themes I would ask them about to make sure, they were okay with the topics and that I was being transparent in my communication. At the end of each interview, I left the final word to them asking for their comments about the interview-experience and if they had anything more to add.

In the field, I approached the teachers as people from whom I could learn something. I chose to be transparent about my presence in the field as a participating observer and researcher to gain access to the activities and people in the field. However, a researcher cannot enter a field without influencing it. This makes it important to reflect on the values, interests and assumptions you bring with you to the field of study. In other words, it is necessary to be mindful of what ways and to what degree you impact the research process (Henriksen, 2003, p. 16). Since I had an interest in finding tensions related to the Science Marathon activity I tried to be mindful that this interest did not result in a narrow outlook. If I only focused on what potential tensions and conflicts might emerge it would prevent me from engaging in the activities being open to the unanticipated. I also needed to reflect on my values about 'good' and 'bad' teaching. Knowing, that the power relation between a researcher and those observed is asymmetrical (Brinkmann, 2020, p. 589), I wanted to avoid imposing my worldview on anybody. Otherwise it could potentially harm my relationship with the teachers. In fact, I needed to revise my values, when I discovered that they were based on naïve assumptions about the teachers' practices. I entered the field with the mantra that I knew nothing about what it felt like being a teacher, which was the truth. I told the teachers that I wanted to follow them because they were the experts, and I wanted to learn from their perspective.

When conducting participant observations I tried to find a balance between distance and closeness in the field in my role as a researcher (Kristiansen & Krogstrup, 1999). On the one hand, I needed to get close to the people in the field to capture the implicit and tacit knowledge, but on the other hand, I needed to be distant to be able to make observations and to remind the informants of the reason why I was there. I did not want to treat the informants as research objects and entered the field with respect for the people I interacted with and connected with them in a friendly manner. I have otherwise attempted to analyse data and report results as accurate as possible and in my writings, I have tried to be transparent about the procedures and methods applied.

4.8. Reflections on research design

In this section, I have some final thoughts about the quality of my research design.

I have tried to present my choices, use of methods and reflections regarding my research design as open and accurate as possible. It is my hope that I have achieved transparency in this process enabling others to assess the trustworthiness of the results. I have accounted for my role as a researcher and made it clear what assumptions and interest I brought with me to the field. I have described my reflections about these biases so they would not affect the participants in the field.

I entered the field with a sense of humbleness. I was grateful to the teachers who opened up their teaching for me and gave me an insight in their daily lives. Through dialogue with the teachers, I wanted to learn how their world looked like since I have regarded it as an important purpose of this study to learn from the teacher's perspectives.

But, the question is, if my research project is valid? Here, I do not regard validity from a quantitative perspective (Kristiansen & Krogstrup, 1999) where a validity criterion for research quality regards whether you measure what you intended to measure. This understanding is problematic if you study a social phenomenon, which essentially cannot be measured (Henriksen, 2003, p. 30). Instead, I regard validity from a qualitative research perspective. Qualitative research is about understanding a phenomenon, which can lead to theory development (Karpatshof, 2020, p. 574). From this perspective, validity means to what extent my research methods and interpretations of data have enabled me to understand the phenomenon under investigation (Kristiansen & Kropgstrup, 1999).

I have described and accounted for my reflections related to the interconnections between my research problem, theoretical approach, and applied research methods. I could possibly have done more to deepen my understanding of the complexities involved with implementing integrated STEM education in schools. For example, had I extended my participant observations to include the teachers' regular teaching activities instead of only focusing on the Science Marathon, I could have developed a more nuanced understanding about how these activities impacted each other. However, since I conducted a case study of the Science Marathon, it seemed at the time sufficient only to participate in activities related to this case. Besides, the teachers continuously told me about their regular teaching activities and I believed what they said matched their subjective experiences.

If time had allowed, I could also have interviewed the rest of the teachers engaged in the Science Marathon at each schools for more perspectives. I could have included other research methods too. From the start of the research process, I intended to conduct a questionnaire targeting all teachers conducting the Science Marathon to triangulate my data. However, due to paternity leave followed by Corona-virus shut down of schools this was not possible. By the time I came back from paternity leave and society had again opened up, my research project was at such a late stage that it was no longer possible for me to design the questionnaire or analyse the data gathered. Had I been able to gather questionnaire data I could have used it as a basis for understanding the four case schools and to triangulate my data which could have provided an impression of how widespread the identified systemic tensions were.

Another qualitative research criteria regard whether the results of the study will have significance for others (Henriksen, 2003). It is my hope that my research can be of practical significance (Tracy, 2010) to the continued implementation of integrated STEM in schools by pointing to systemic contradictions. Thus, the impact of this study must be judged by its usefulness regarding future implementation of integrated STEM activities in schools.

I presented to my research group and other relevant researchers my preliminary analysis and results to discuss and interpret these together, which I have regarded as a peer-validation (Henriksen, 2003). Due to the consistency with which I have approached the analysis of my data, I believe it would be possible for another researcher with knowledge about the theoretical framework and methodology applied to conduct a new thematic analysis of the data and achieve, not identical results, but themes that would be similar to the ones that my results build on.

In the next chapter, I present the overall conclusion of this PhD project.

5. Conclusion

In this thesis, I asked what systemic contradictions mediated the implementation of integrated STEM education in comprehensive schools in Denmark. I conducted a case study based on qualitative research methods to explore how groups of teachers participated in the educational program Science Marathon in four different school settings applying activity theory as a theoretical approach. I analysed how the teachers conducted the Science Marathon activity, which I have argued represents a more generalised object of implementing integrated STEM in comprehensive schools.

Based on the four papers that constitute the main contributions of this thesis, I will now describe and explain the systemic contradictions regarding implementation of integrated STEM in schools, identified through the four school cases. Based on my findings, I will consider the consequences for the widespread implementation of integrated STEM education in schools. I will also discuss perspectives for future research focused on overcoming these systemic contradictions to support successful implementation.

5.1. The subject's interpretation of the object

In the next sections, I will describe and explain the systemic contradictions that emerged as tensions mediating the relation between the subject and the object in the Science Marathon activities at each school. Here, the subject refers to the groups of teachers at each school engaged in the Science Marathon, and the object refers to what it means to conduct the Science Marathon as a teaching activity from the group of teachers' perspective and represents what they wanted to accomplish by engaging in the activity.

I will introduce three fundamentally different explanations for how the subject interpreted the object as approaches to science teaching and learning, as approaches to competence-based learning and finally as approaches to achieving 21st century skills. In each section, I will describe how systemic contradictions influence the different interpretations of the object and argue why this poses barriers for the implementation of integrated STEM. Finally, I will argue that the large variation in the interpretations of the object poses a systemic contradiction it itself.

5.1.1. The object interpreted as aimed at science teaching and learning

The groups of teachers engaged in Science Marathon interpreted this activity as an approach enabling them to aim predominantly at science teaching and learning. From an activity-theoretical perspective, this meant that the subject interpreted the object related to the S in STEM.

Even though the subject completed the Science Marathon as a team of teachers with different disciplinary backgrounds in each school (except S4), they did not necessarily regard the object as an interdisciplinary activity. Even though an engineering design process was applied as the main tool to mediate the Science Marathon activity, and both mathematics, and craft and design were explicitly mentioned in the description of the Science Marathon program, many of the teachers remained focused on the science aspect of STEM. This particular interpretation of the object was present at three out of four schools and mediated by different tensions in the activity systems at each school.

The one school (S3) that did not share this predominant interpretation differed significantly from the other schools. For example, the school curriculum had been reorganized to include a weekly project day, yielding more time for teachers to plan teaching activities together. A so-called 'FabLab' (Fabrication Laboratory) had been built as an integrated part of the pedagogical learning centre in the school, giving teachers and students access to many advanced technologies. Moreover, a specific approach based on design learning called the 'design-circle' had been adopted by all members of the school as a tool to mediate project-based and problem-based teaching activities. To make sure all teachers were able to use this tool in their project-based teaching activities, teachers had received training related to this design approach. From an activity theoretical perspective, this school had undergone a collective transformation to enable more problem-based teaching aimed at technological literacy and 21st century skills. These particular school settings influenced the Science Marathon activity by enabling the 5th grade teacher team (the subject), to interpret and accomplish the activity as a transdisciplinary approach aimed at developing 21st century skills without mediating tensions.

At the schools where the teachers predominantly interpreted Science Marathon as an approach aimed at learning science, tensions within each activity system mediated this particular interpretation. For example, in school (S1), components of division of labour and rules influenced the subject's relation to the object by creating tension within the subject component. The middle-school teacher team (the subject), interpreted the object from different perspectives determined by whether they taught nature/technology or not. The science teachers interpreted the object as an interdisciplinary approach aimed at developing complex skills such as problem solving and collaboration, although they also maintained focus on science as the main learning goal. However, the other teachers, who taught subjects such as mathematics, and craft and design, interpreted the object as exclusively aiming to teach students science content. Unequal responsibilities among the teachers (division of labour) and the school tradition of referring to Science Marathon as a 'science week' (rules) strengthened the tension in the subject component.

This tension made it difficult for the teachers not teaching nature/technology to see how they could contribute with anything but the extra lessons they provided, despite that fact that their subjects were included in the Science Marathon program.

The historical evolvement of the Science Marathon program and the National curriculum for comprehensive school influenced why the majority of the teachers maintained that the object in the Science Marathon activity was to achieve science learning.

Focusing on the historical evolvement of the Science Marathon program, it initially aimed exclusively at achieving the objectives of the nature/technology curriculum. It was not until 2018 that the engineering design process model was adopted as the main approach in Science Marathon. By adopting this new tool, the Science Marathon program expanded its object from being a science-based activity to being more of an integrated STEM activity. However, since engineering is not a subject in the curriculum of comprehensive schools, there are no formal objectives for engineering. As implementation of engineering in comprehensive schools is still relatively undefined, the teachers engaged in the Science Marathon activity had limited prior knowledge of working with the engineering design process and the epistemological practices that it represents.

These cultural-historical developments influenced the Science Marathon activities in each school. Here, the engineering design process model (cultural artefact) intended to mediate the Science Marathon activity as an integrated STEM approach collided with the lack of engineering objectives in the national curriculum (rules) and with the historic object of defining Science Marathon as an exclusive nature/technology program causing tension for the teachers. Consequently, there was a systemic contradiction across the activity systems, and this could explain why the teachers predominantly interpreted the object to be mainly about teaching science and not integrated STEM. An exception to this pattern was at school (S3), where the school community had overcome this systemic contradiction through organizational changes such as collective implementation of the 'design circle', which is an inherently interdisciplinary approach that meant that the teachers had better preconditions for understanding the engineering design process model and for engaging in interdisciplinary collaborations.

The teachers' interpretation of the object as predominantly aimed at the S in STEM corresponded well with the STEM literature where science often is described as the dominating discipline (Wong et al., 2016). The teachers predominantly applied the engineering design process model in Science Marathon as a tool to mediate science teaching and learning. This also corresponded with the literature suggesting that engineering quickly becomes an application of science in integrated STEM (Kloser et al., 2018). However, in the Science Marathon activities this is not surprising, since engineering does not constitute a distinct subject in the national curriculum for comprehensive schools. Nevertheless, both the mathematics, and craft and design subjects involved in Science Marathon constitute distinct subjects with formal objectives in the curriculum. Still, the teachers either ignored them or only regarded them as a support for science learning.

This systemic contradiction impeded some of the teachers from engaging effectively in interdisciplinary collaboration, depending on the local school settings. Accordingly, teachers with different disciplinary backgrounds were challenged to agree on the object of the activity. Consequently, teachers not normally covering nature/technology had difficulties in seeing how they could meaningfully participate in an activity defined as science. Accordingly, this systemic contradiction could result in the loss of interdisciplinary learning opportunities for students, or teachers may become reluctant to teach integrated STEM, at least not as a team. Since research suggests that it would be very difficult for an individual teacher to carry out integrated STEM alone (Sanders, 2009), this is a crucial barrier to implementation and it points to the importance of reflecting and communicating about what goals to achieve through integrated STEM.

I would therefore suggest that, to avoid alienating some teachers, future research should focus on how to stage integrated STEM as a more inclusive agenda, not only relevant for science. As demonstrated by the activity system at school (S3), systemic contradictions influencing interdisciplinary collaboration can be overcome, provided teachers are supported by the cultural-historical settings of the school.

Systemic contradiction also created a tension regarding epistemological practices related to students' understanding of the distinct disciplinary practices attached to each subject. It is important to be mindful not to overlook any subjects involved when conducting integrated STEM teaching. In an integrated STEM curriculum, there is a risk of losing sight of these distinct disciplinary features, and this is a well-known dilemma in much interdisciplinary teaching (Dolin, 2018; Sillasen & Linderoth, 2017). The dilemma is that, although it is important to respect the epistemological practices of each subject, it is also important not to end up with an overwhelmingly long list of goals to be achieved. So, the question is whether or not we can afford to focus on the epistemological practices of each of the disciplines in integrated STEM. As there is no overall solution to this dilemma, it must be solved on a case-by-case basis trying to meet both demands.

5.1.2. The object interpreted as competence-based teaching and learning

Many of the teachers at each school interpreted the object of Science Marathon to be authentic problem solving aimed at developing student competence. From the perspective of activity theory, the engineering design process represents the artefact mediating this interpretation.

However, across schools the teachers agreed that competence-based approaches to instruction were difficult to implement in their normal teaching. How meaningful the groups of teachers, (the subject), perceived this approach to be varied between the activity systems of each school.

The cultural practices of the comprehensive school system can explain why some of the teachers aimed for subject content and not competence.

Since the school reform in 2014, the national curriculum has been a competence-based curriculum. However, up until 2014, the formal objectives in the curriculum for comprehensive schools were mainly based on student acquisition of knowledge. Despite the recent implementation of competence-based objectives in the curriculum, many of the cultural practices in schools are still based on disciplinary understandings based on knowledge acquisition (Daugbjerg et al. (2018). Among prevailing practices detrimental to competence-based learning are schools organized in separate science subjects with a very limited number of lessons per week, discrepancies between competence-based objectives and assessment practices (Dolin et al. 2017), and not enough time allocated for teachers to collaborate and plan teaching together (Daugbjerg et al., 2018). These school practices conflict with teachers' attempts to implement competence-based approaches.

These cultural practices of the comprehensive school system thus constitute a systemic contradiction that manifests itself as tensions in the activity systems between rules and artefact mediating the relation between subject and object. Here, rules refer to the norms, traditions and values of teaching and learning, and artefact refers to the engineering design process model associated with authentic problem solving. Although this conflict manifested itself at all schools, there was much variation in the extent to which it was allowed to influence the relation between subject and object in the Science Marathon activities. Nevertheless, this explains why some of the teachers in Science Marathon referred to the curriculum, as they emphasized content over competences.

At schools (S3) and (S4), the teachers involved in the Science Marathon activity described that their day-to-day teaching activities aimed predominantly at competence-based approaches. Particularly in school (S4), the teachers described their regular teaching activities regarding science as based on authentic inquiries aimed for developing student science competences[1]. Nevertheless, they perceived having to choose between content and competences in their day-to-day teaching activities as a dilemma. They aimed to focus on competences because their own values and beliefs aligned with competence-based learning. However, they often felt discouraged by existing assessment practices designed to capture knowledge rather than competences, thereby contradicting their ambitions to teach competence-based. Being used to engaging in authentic problem-solving activities mediated these teachers' understanding of Science Marathon as an approach based on authentic problem solving aiming at developing student competences. They described this approach as a meaningful and engaging learning process resulting in increased student motivation to learn, more interest in science and a deeper understanding of the subject content. The outcome of the Science Marathon activity at school (S4) and (S3) was not new practices among the teachers but rather confirmation that what they were already doing was meaningful and worth pursuing, in spite of the systemic pressure to also teaching subject content. In this regard, their regular science teaching activities and Science Marathon were oriented towards the same object of teaching based on authentic problem solving to aim for science competences. Thus, their teaching activities and Science Marathon aligned with each other and caused no tensions.

At two other schools (S1 and S2), many of teachers' regular teaching activities were based on covering subject-content. These teaching activities were mediated by norms and traditions at the schools (rules), which also influenced the teachers' way of relating to Science Marathon as an artefact based on authentic problem solving. Consequently, they struggled to recognize what the students learned from Science Marathon because the contradiction between rules and artefact resulted in them not knowing what to look for. Mediated by their norms for teaching and learning, they focused on whether the students could explain subject-specific concepts as an indicator for whether they had learned anything. As these norms conflicted with the artefact applied in the Science Marathon mediating competence-based learning. As a result, the teachers

[1] Please note that an activity systems analysis of the Science Marathon activity in school (S4) is not included in full in any of the papers of this thesis. The data gathered from this school only figures in paper 4 (Waaddegaard, submitted), which is a thematic analysis focusing on themes found across schools, thereby not focusing on the activity systems relations. When providing specific examples from the activity system at school (S4) this is to be considered as supplementary activity systems analysis.

perceived the students' learning outcome in Science Marathon as limited. At the same time, they also said that they were proud of how their students had performed so independently, supported each other in the process, worked systematically and gained knowledge. This indicated that the outcome of the activity had also resulted in teachers discovering that authentic problem solving as an approach to learning was meaningful, and thereby questioning the rules in the system.

If they could overcome the systemic contradiction between rules and artefact it could open up for the possibility of adopting the engineering design process model and other similar problem-based approaches in their regular teaching activities, thereby expanding the object in their regular activities to include competences. However, if this contradiction is not resolved, this expansion is unlikely to happen.

Although the Science Marathon provided the teachers with opportunities to apply more competence-based approaches, the systemic contradiction manifested itself as conflicts between rules and artefacts in the Science Marathon activities.

In the literature about integrated STEM, many texts refer to the traditional curriculum as resilient to changes causing a significant barrier to implementing integrated STEM in Schools (Blackley & Howell, 2015; Williams, 2011; Sanders, 2009). The findings in this study similarly suggest that many of the cultural practices of the school impede teachers from developing authentic problem-solving approaches aimed at competence-based learning in their day-to-day teaching activities. Holmlund et al (2018) concluded that teachers teaching integrated STEM in traditional schools were not likely to continue to pursue these activities. Similarly, my findings suggest that teachers in schools mediated by values and norms based on knowledge acquisition are not likely to continue with integrated STEM teaching beyond the Science Marathon, as long as this contradiction exists.

This systemic contradiction relates to the dilemma that teachers are encouraged to focus on both competences and on knowledge acquisition as two opposites by the systemic structures. However, Ropohl et al. (2017, p. 20) described that responding to a problem competently requires application of knowledge. This demonstrates that knowledge and competences are intertwined and not necessarily conflicting. Nevertheless, the results of this study demonstrate that teachers feel caught between two different ways of understanding teaching and learning perceived as incompatible.

Elmose (2016; 2018) ascertained that the concept of science competence lacked definition in the science curriculum. As the concept thereby appears unclear, the responsibility for operationalising and understanding what it means falls on teachers (Elmose, 2018).

Furthermore, many existing assessment practices in the educational system are based on summative tests that are not capable of assessing student competences, and such assessment practices promote teaching for knowledge acquisition and rote learning (Dolin & Nielsen, 2017, pp. 8,10). In the school year 2015/2016, a new interdisciplinary oral examination was implemented in grades 7-9 supported by six problem-based teaching sequences to promote science competence and integration of science subjects (Daugbjerg et al., 2018). However, some teachers experienced this examination and the teaching sequences as an 'add-on' to the existing curriculum without allocation of the extra time required for teachers (Krogh et al., 2018). In fact, Daugbjerg and Krogh (2018) showed it is especially difficult for teachers to find the time to collaborate with colleagues about shared teaching practices. As a result, teachers are under a lot of pressure to ensure that students develop competences and at the same time acquire subject knowledge.

From this perspective, it is no wonder that teachers lack confidence regarding how to operationalise competences. Just as it is not surprising that they fall back on the aim for content-based learning, because it is more familiar and easier to aim for in a school system that puts immense pressure on teachers. It also means that, even though integrated STEM teaching can be interpreted as ways to operationalise competences, the outcome is not necessarily a competence-based teaching practice, if neither teachers nor school system have the capacity to accomplish these goals.

To overcome this systemic contradiction, I would suggest that future research focused on how to support teachers in developing a shared language about competences in integrated STEM. Ways to achieve this would be by facilitating better opportunities for teacher collaboration to discuss and reflect on competence-based teaching and learning (Nielsen & Dolin, 2016). This would require allocating more time for teacher team meetings. I would also suggest that future research should focus on developing and testing assessment practices that support integrated STEM teaching and learning as well as finding ways of implementing these practices without imposing more demands on teachers.

5.1.3. The object interpreted as 21st century skills

There were teachers who interpreted the object of Science Marathon as an opportunity to develop a range of 21st century skills. However, the teachers' perceptions of these skills were vaguely defined, and they had difficulties formulating these as concrete learning goals. Even though the teachers frequently mentioned many different 21st century skills as pertinent to Science Marathon, collaboration was the only skill all teachers mentioned consistently.

The reason why the teachers both perceived these skills as important but also defined them inconsistently lies in the systemic contradiction, mediating the teachers' interpretation of the object in Science Marathon.

Skills resonating with 21st century skills are included in the curriculum for comprehensive schools. For example, in the science curriculum, collaboration and creativity skills are part of the purpose of the nature/technology subject (Ministry of Children and Education, 2019a). Moreover, a cross-curricular goal called 'innovation and entrepreneurship' focuses on 'innovation-competence', 'creativity and action-oriented competences', 'collaboration skills' and 'persistence' through innovative processes (Ministry of Children and Education, 2019, p. 99-100). On the one hand, these skills are presented as important, but on the other, they lack clear definition. They are not like the concrete competence-based objectives that otherwise constitute the curriculum structure.

Thus, the curriculum sends mixed messages regarding these skills, manifested as tension representing this ambivalence in the rule component in the Science Marathon activity systems. This ambivalence mediated the teachers' interpretation of the object as approaches aimed towards achieving these skills. The way this mediation influenced the teachers' interpretation of the object included a display of ambivalence regarding whether 21st century skills were the means to achieving other learning goals or whether they were the learning goals themselves. In other words, it was unclear whether the teachers perceived collaboration skills as a precondition for engaging in and achieving other learning goals in Science Marathon, or whether collaboration skills themselves were the learning goal. When the object in Science Marathon was related to 21st century skills, it remained unclear how the teachers defined these skills and how to support students to develop them. Consequently, even though the teachers interpreted 21st century skills as relevant in Science Marathon, if and how they intended to operationalise these skills remained unclear.

These findings confirmed that integrated STEM offers opportunities to promote 21st century skills (Bybee, 2010; Guzey et al., 2020). However, the findings also confirmed, that it is difficult for teachers to aim for 21st century skills in teaching, since these skills are often ill-defined, and teachers are expected to determine their meaning themselves (Ananiadou & Claro, 2009).

The systemic contradiction is whether 21st century skills are to be considered important learning outcomes. And if so, how can these skills be trained and defined as explicit learning goals in integrated STEM? It is not enough for integrated STEM to provide opportunities for promoting 21st century skills if teachers are unable to operationalize them: regardless of whether they perceive them as relevant. As long as it remains unclear what 21st century skills encompass, they will remain as arbitrary learning outcomes whose importance is rather questionable.

To overcome this systemic contradiction, I suggest that future research focusses on how to support teachers in defining 21st century skills relevant for integrated STEM teaching, thereby enabling teachers to turn these skills into realizable learning goals and signs of learning. I would also suggest to develop assessment practices aligned with 21st century skills to signal their importance.

Nielsen (2015) conducted a study aimed at developing a tool to assess innovation competence in upper-secondary schools. Through teacher talk, Nielsen (2015) developed a list of potential assessment criteria for innovation competence perceived as a meaningful tool by the teachers. This study shows that is possible to develop useful tools enabling teachers to aim for 21st century skills in their teaching practices and to assess whether students improve on any of these skills.

5.1.4. The object interpreted as multi-facetted

Looking across the teachers' interpretations of the object in Science Marathon reveals that the object in integrated STEM is multi-faceted and difficult to define. This can mean many different things, depending on the settings. This is in itself a systemic contradiction with implications for the implementation of integrated STEM in schools, because when it is possible to interpret the object in so many different ways, the object becomes ambiguous. On the one hand, it enables teachers to determine what integrated STEM means in their settings and what they want to achieve with it. However, on the other hand, this study has shown that it also means that integrated STEM becomes a confusing construct surrounded by uncertainties about what goals to aim for, what integrated STEM is about, and how it is related to other school agendas. This point is supported by the literature, where integrated STEM emerges with many different interpretations, making it a rather ill-defined concept (Wong et al., 2016; Bybee, 2010; Blackley & Howell, 2015). If we could develop more clarity about what integrated STEM constitutes, then it would become easier for schools to implement it as intended.

5.2. Local settings influencing the activity

In this study, I have identified tensions within the Science Marathon activity systems mediating how the teachers interpret and complete the activity. These tensions are manifestations of systemic contradictions that teachers alone are not able to resolve. They extend beyond the individual teachers and constitute barriers to implementing integrated STEM education in comprehensive schools.

The outcome of the Science Marathon activities varied among the four schools, depending on how strongly the systemic contradictions manifested themselves in each school and how much they mediated the relation between subject and object. How deep-rooted these contradictions were depended on the local activity systems and the school settings that mediated the Science Marathon activities by either reinforcing or reducing systemic contradictions.

This shows that the local school settings play a huge role for teachers' possibilities and challenges regarding successful implementation of integrated STEM activities. In other words, local school settings mediate teachers' abilities to implement integrated STEM education. Among the local settings that mediated the teachers' activities, besides those already mentioned, were school management, other school agendas, the physical distances between lab-rooms and classrooms, having access to teacher training, having science coordinators employed as teachers, shared values regarding teacher collaboration, having enough time to prepare teaching, assessment practices, and the composition of the students. All these factors have in common that they extend way beyond the Science Marathon activity systems, but they are still are part of what mediates this activity.

These examples show how complex it can be to overcome these systemic contradictions so that it is possible to implement integrated STEM activities as intended. For example, at school (S2), the school management had an ambition to promote professional learning communities as the model for teacher collaboration in teams. However, the management had not allocated enough time for the teachers to meet with their teams to focus on developing shared goals. Consequently, the teachers did not recognize this ambition. This influenced the division of labour in Science Marathon, as the teachers for the most part neither planned nor taught the program as a team and only relied on each other when sharing materials. This contrasts with school (S3), who had taken steps to promote problem-based teaching as described above. The teachers from these two schools had completely different conditions for implementing integrated STEM in their teaching practices due to the local settings of each school.

These examples illustrate how individual teachers alone are unlikely to be able to overcome the complex systemic contradictions. Instead, a collective effort is required that involve the entire school. In fact, it involves the entire comprehensive school system. This collective level of is important to include in any solutions aimed at implementing integrated STEM education. Therefore, it is not only problematic, but also counterproductive to think that teachers are solely responsible for this, as this study has shown that so many other cultural-historical aspects mediate this activity.

5.3. Summary

To summarize; the answer to my research question is that the systemic contradictions that mediated the implementation of integrated STEM were:

Approaching integrated STEM as science teaching or interdisciplinary teaching

- School practices mediated that teachers with different disciplinary backgrounds were challenged to agree on the object of the activity in some schools.
- Teachers not normally covering nature/technology were challenged to perceive how they could meaningfully participate in an activity defined as science, and this posed a barrier to interdisciplinary teacher collaborations.

Distinguishing between science and engineering practices

- Lack of clarity regarding the engineering design process meant that teachers had difficulty distinguishing the differences and similarities between science and engineering practices.

Teaching for science competence or content

- Some existing school practices mediated the object of some activity systems towards acquisition of knowledge.
- Some teachers lacked understanding of how to promote and recognise student competences, which posed a barrier to perceiving student outcomes of Science Marathon as meaningful learning.

21st century skills as relevant but vague goals

- Teachers felt ambiguous with regard to the 21st century skills as relevant objects for Science Marathon. Although the teachers interpreted 21st century skills as relevant, they were challenged in realizing them as specific learning goals.

Inconsistency of integrated STEM object leads to varying teaching practices

- The object of the activity in each school was interpreted in many ways, which in itself mediated a perception of integrated STEM as an elusive activity with unclear goals.

Integrated STEM object compatibility with local school settings

- Local school settings and practices mediated the subject's relationship to the object, suggesting that teachers are unlikely to be able to implement integrated STEM on their own.

With this research project, I have provided a systemic perspective on the implementation of integrated STEM in comprehensive schools. Many of the identified contradictions mediating the implementation of integrated STEM have previously been researched as isolated barriers. However, my research contribution is to provide a systemic overview of the barriers that arise from systemic contradictions. This knowledge can help identify areas requiring attention in order to overcome barriers to implementing integrated STEM.

I have pointed out that teachers have different interpretations of what it means to teach integrated STEM and it is important that they can agree on an interpretation. I have also pointed to how local school settings play a crucial role, potentially impeding teachers from implementing integrated STEM as intended. We need to take into careful consideration these systemic contradictions as they appear in their local contextual settings if we are ever to achieve large-scale implementation of integrated STEM. If we do not, we cannot expect to achieve the type of expansive learning necessary to implement integrated STEM as a regular part of teaching in comprehensive schools. Accordingly, future research must focus on finding ways to overcome the identified systemic contradictions.

6. References

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7. Papers included in this thesis

7.1. Paper 1

Sølberg, J., & Waaddegaard, N. (2019). Hvad ved vi om indsatser inden for engineering i den danske grundskole gennem de sidste 10 år? *MONA - Matematik- Og Naturfagsdidaktik*, 2019(2), 31-47.

Abstract

Denne artikel præsenterer de væsentligste resultater af en omfattende kortlægning af engineering (og lignende) indsatser i den danske grundskole gennem de sidste ti år. I artiklen anlægges et bredt perspektiv på hvordan engineering kan forstås i en dansk sammenhæng. I alt 582 indsatser indgik i undersøgelsen, og 32 af disse blev analyseret grundigt for gennemgående tematikker. Artiklen fokuserer på udvalgte resultater fra kortlægningen som er opdelt i afsnit der beskriver hvordan engineering berører henholdsvis elever og lærere. Artiklen indeholder desuden konkrete anbefalinger til naturfagslærere og projektmagere der beskæftiger sig med engineering.

7.2. Paper 2

Sølberg, J., & Waaddegaard, N. (2022). Naturfagslæreres udfordringer med kompetencer. In Fougt, Bundsgaard, Hanghøj & Misfeldt (Eds.) Håndbog i scenariedidaktik (pp. 247-257). Aarhus Universitetsforlag.

Abstract

Dette kapitel belyser udfordringer for lærerne ved kompetenceorienteret naturfagsundervisning i 5.-6. klasse gennem det såkaldte Naturfagsmaraton, en årligt tilbagevendende konkurrence med klare scenariedidaktiske træk. I analysen anlægger vi et virksomhedsteoretisk perspektiv for at belyse de modsigelser, som opstod på tre forskellige skoler i forbindelse med forløbet, hvilket peger på lærernes muligheder for at realisere kompetenceorienteret naturfagsundervisning mere generelt. Casene illustrerer forskellige strukturelle udfordringer, som kan forhindre lærere i at gennemføre kompetenceorienteret undervisning. Samtidig peger casene på et dobbelt sigte med naturfagsundervisningen, som lærerne i varierende grad kæmper med. Det ene sigte italesættes som ansvaret for at sikre, at eleverne tilegner sig fagspecifik viden. Det andet er rettet mod, at eleverne udvikler mere generiske kompetencer såsom samarbejdsevner, der rækker ud over de naturfaglige kompetencer. Med udgangspunkt i en virksomhedsteoretisk analyse af Naturfagsmaraton bidrager kapitlet med et organisatorisk perspektiv på scenariedidaktik og de organisatoriske udfordringer, der kan være afgørende for, hvordan scenariedidaktik kan udfoldes i undervisningen.

7.3. Paper 3

Waaddegaard, N., & Sølberg, J. (submitted to the journal 'Mind, Culture and Activity'). A cultural-historical perspective on integrated STEM education in Danish middle schools.

Abstract

Integrated STEM (Science, Technology, Engineering and Mathematics) education gains momentum in Denmark. However, achieving integrated STEM education remains a challenge for many teachers in middle schools. In order to achieve a more widespread implementation of integrated STEM education, it is vital to understand the barriers to implementation in schools. To understand the complexities involved for teachers, we applied cultural-historical activity theory to examine emerging contradictions when teachers teach integrated STEM in Danish middle schools. We conducted participant observations and semi-structured interviews with teachers and school leaders in two schools involved in an integrated STEM program called "Science Marathon". The results showed that Science Marathon gave teachers legitimacy and opportunity to spend the time and resources necessary to conduct integrated STEM teaching. However, teachers experienced tensions between an integrated STEM approach and a content-focused perception of the National curriculum. We discuss these tensions as manifestations of curriculum-related contradictory ambitions as they emerged in the teachers' practices when carrying out Science Marathon. Accordingly, a segregated curriculum with traditional pedagogies collided with an integrated curriculum with student-centered pedagogies. If integrated STEM education is to become a widespread activity in Danish middle schools, we need to consider these curricular contradictions.

7.4. Paper 4

Waaddegaard, N. (submitted to 'International Journal of STEM Education'). Teachers' perceived learning goals for integrated STEM Education in Danish Schools.

Abstract

Background: Integrated STEM education permeates policies and national curricula across the globe, yet it is not always clear what STEM education is and which aims are pursued in STEM instruction. This paper explores teachers' perception of the most prevalent learning goals when teaching integrated STEM in a Danish school context. The paper reports from a case study of the Danish nationwide STEM programme called the Science Marathon, in which students work in groups to solve an engineering challenge. Through participant observations and qualitative interviews, 12 teachers from four different schools were followed while they conducted the Science Marathon in classrooms. The data gathered was subject to a thematic analysis focusing on the teachers' accounts of what they perceived as important learning goals related to the Science Marathon programme.

Results: The results showed that the teachers participating in the Science Marathon considered ambitions corresponding to the listed integrated STEM educational goals as important. They perceived authentic problem solving, collaboration skills and scientific competence as important goals to aim for. However, they also described difficulties aiming for these goals due to their focus on teaching for subject content, ill-defined learning goals, and school structures preventing them from realising their integrated STEM ambitions.

Conclusion: This article showed that even though the teachers in the study perceived many integrated STEM ambitions as relevant, there was an inconsistency between what they perceived as important learning what they aimed for in their instruction. The implications of this article point to the necessity of clearly define specific learning goals to attain in integrated STEM instruction to help teachers realising the integrated STEM ambitions.