UiT The Arctic University of Norway

Department of Education

Teaching science with students in mind

Pre-service science teachers' knowledge and teaching practices

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A dissertation for the degree of Philosophiae Doctor - June 2021

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Summary

With this thesis, I address gaps in research about how pre-service teachers (PSTs) develop and make use of knowledge for science teaching. In the project I used a qualitative case study approach to investigate seven PSTs' science teaching, their use of pedagogical content knowledge (PCK) for pedagogical reasoning, and the sources contributing to their development of PCK. I explored how PSTs develop knowledge about students and instructional strategies. I also examined how they enacted these components of PCK.

I videotaped the PSTs' science teaching in grade 6–10 school practica in the first and third years of teacher education. I analyzed the videos to identify dimensions of quality instruction related to PCK. In their first-year school practica, the PSTs' science instruction was student-centered, focusing on students' prior knowledge and classroom discourse. However, the PSTs struggled to clearly communicate science concepts, and inquiry teaching was almost absent. In stimulated recall interviews performed shortly after some of the lessons, I used video recordings to prompt the PSTs to reconstruct thinking from the lessons. In their reflections, the PSTs shared nuanced knowledge about students, which informed their student-centered instruction with suitable instructional strategies. Specialized science courses, PST peers, and personal learning experiences were central sources of their PCK.

I repeated video observations and stimulated recall interviews with three PSTs in third-year school practica. I examined whether and how experiences from specialized science teacher education courses, which intertwine content knowledge and PCK, made a difference in their classroom teaching. By comparing lessons, I found the PSTs' instructional strategies and their reasons for selecting them were more grounded in science PCK and less in general pedagogy when they were teaching topics they had learned in specialized science courses. The PSTs viewed these courses as supporting their development of content knowledge, PCK, and self-efficacy for science teaching. Implications for teacher education includes that pre-service teachers' prior knowledge of teaching may be a useful starting point for professional development, and teacher education courses that combine science and pedagogy seem to benefit PSTs when paired with opportunities to teach the same topics in school practica.

Samandrag

Gjennom denne doktorgradsavhandlinga addresserar eg eit behov for forsking på korleis lærarstudentar utviklar og gjer seg bruk av fagdidaktisk kunnskap om naturfagundervising. Prosjektet vart gjennomført som ein kasusstudie av sju lærarstudentar si undervising i praksis på 6.-10. trinn på fyrste og tredje år i lærarutdanninga. Gjennom videoobservasjonar og intervju studerte eg korleis lærarstudentane utvikla kunnskap om elevar og kunnskap om undervisingsmetodar, og korleis dei sette slik kunnskap i verk i klasserommet.

Videoopptak av all naturfagundervising til seks lærarstudentar første studieåret vart analysert ut frå ulike dimensjonar av kvalitetsundervisning, knytt til fagdidaktisk kunnskap. Undervisinga var elevsentrert. Det innebar at lærarstudentane la vekt på elevane sin tidlegare kunnskap og la til rette for opne samtalar om emnet i klasserommet. Lærarstudentane strevde med å formidla naturfagleg innhald tydeleg, og elevane fekk sjeldan høve til å utforska. I stimulerte gjenkallingsintervju kort tid etter nokre av timane gjengav lærarstudentar tenking frå situasjonane i klasserommet medan dei såg opptak frå timen. Lærarstudentane hadde nyansert kunnskap om elevane, og brukte denne kunnskapen til å gjera undervisinga elevsentrert, og ta i bruk høvelege undervisingsmetodar. Lærarstudentane oppgav at dei hadde slik samankopla kunnskap om elevar og undervisingsmetodar frå fagdidaktiske lærarutdanningskurs, medstudentar, og eigne erfaringar med læring.

I tredjeårspraksis gjentok eg videoobservasjonar og stimulerte gjenkallingsintervju av tre lærarstudentar. Eg undersøkte om og korleis fagdidaktiske kurs frå lærarutdanninga hadde innverknad på undervisning i klasserommet. Resultat frå denne samanliknande studien viste at kursa utgjorde ein positiv skilnad. Særskilt var undervisingsmetodar og grunngjevingar for val av desse kopla meir til fagdidaktikk enn generell pedagogikk når lærarstudentane underviste i emne dei hadde hatt i fagdidaktiske kurs. Lærarstudentane oppfatta desse kursa som nyttige for eiga utvikling av kunnskap om fag og didaktikk og tru på eiga meistring i utøving av yrket. Funn frå prosjektet peikar mot at lærarutdannarar med fordel kan dra nytte av lærarstudentar sine tidlegare læringserfaringar. Funna viser òg at fagdidaktiske kurs er til nytte for lærarstudentane, særleg dersom dei får høve til å undervisa i dei same emna i praksis.

Acknowledgements

I want to thank the people and institutions whose shoulders I stand on. First, a special thanks to my main supervisor Magne Olufsen for your advice and steadfast efforts to take the project in a meaningful direction. I have learned so much from you during my work with the master’s and PhD theses. Thanks to Solveig Karlsen for always being available for discussion and your support as supervisor. I appreciate being welcomed into the community of science teacher educators at UiT The Arctic University of Norway.

Patricia Friedrichsen, I was honored and encouraged by your interest in my project and willingness to support a PhD student from the High North. Your contributions during our stay in Columbia, MO and later as third supervisor has been a major motivation and reason for the existence of this thesis.

I want to thank the group of pre-service teachers for taking time to participate in this project through a large part of your teacher education program. I wish you the best of luck with completing your master’s degree in education.

I am the first person to get the opportunity to take a PhD based on the 5-year teacher education program for grade 5–10 at UiT The Arctic University of Norway. After nine years with opportunities to develop as a teacher and researcher, I am thankful to the institution.

Collaborations with the LISSI project group at The University of Oslo has been a major inspiration. I have benefited from the team's expertise in science teaching and video technology.

Many people have supported me and provided constructive criticism. Thanks to my colleagues at the office for helping me structure my days and for interesting conversations. The NAFOL research school have provided me with opportunities for professional development and networking, funding for my research stay in the US, and a useful process seminar with Pernilla Nilsson. For that, I am thankful.

Martha, your love and faithfulness means more to me and my work than you know. Aslak and Inga, the time I spend with you is what gives me joy in life. To my church family in Fjellheim Misjonsforsamling, thank you for bringing grace into my life.

Tromsø, Norway, June 2021

Johannes Sæleset

List of papers

Paper 1. Sæleset, J., Olufsen, M., & Karlsen, S. (Under review). Quality of beginner pre-service teachers' science instruction. *Acta Didactica Norden.*

Paper 2. Sæleset, J., & Friedrichsen, P. (2021). Pre-service science teachers' pedagogical content knowledge integration of students' understanding in science and instructional strategies. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(5). https://doi.org/10.29333/ejmste/10859

Paper 3. Sæleset, J. & Friedrichsen, P. (Under review). A case study of specialized science courses in teacher education and their impact on classroom teaching. *Journal of Science Teacher Education.*

1 Introduction

In this thesis, I will present and discuss the findings of my investigations into how pre-service teachers' (PSTs) enact pedagogical content knowledge (PCK) as they teach science lessons in school practica. The thesis adds to the current understanding of how PSTs develop knowledge and apply it to provide quality instruction. In the introduction, I locate the project within the research on teacher education and argue for its importance. Then, I present the purpose of the study, the two overarching research questions, and the structure of the thesis.

1.1 Background and objectives

Our educational systems serve various ends. Biesta (2009) identified three purposes of education: qualification, socialization, and subjectification. Qualification, the only of the three focused upon in the current thesis, is a major function of education. It includes providing students with knowledge, skills, and understanding that enables them to perform certain actions (Biesta, 2009). Science education, for example, aims to qualify students to be scientifically literate and thereby take informed personal decisions about science-related issues (Roberts & Bybee, 2014).

School teachers are known to play a critical role in the development of students' scientific literacy (OECD, 2005; van Driel et al., 2014) through quality science instruction (Kunter et al., 2013; Seidel & Shavelson, 2007). Their instructional practices are informed by knowledge for teaching (Chan & Hume, 2019; Todorova et al., 2017; van Driel et al., 2014). The current study focuses on the dialectics between teachers' knowledge and instruction.

Since the invention of schools hundreds of years ago, content knowledge (CK) and pedagogical knowledge (PK) were intertwined. In the context of an educational institution, a master was an expert in both content and pedagogy. During the last few centuries, these have been separated into distinct knowledge bases, and education communities have focused on one or the other (Shulman, 1986). In recent decades, researchers have turned their focus toward a component of teacher knowledge that received little attention after the separation of CK and PK. Lee Shulman (1987) conceptualized this "missing paradigm" as PCK, defined as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8). PCK is shaped by a teacher's CK, PK, and context knowledge (Grossman, 1990). It refers to how specific science subjects are taught to specific students (Magnusson et al., 1999; Shulman, 1987) in order to result in learning (Kind & Chan, 2019).

The current thesis focuses on how pre-service science teachers enact their first pieces of professional knowledge, especially PCK. I draw upon the refined consensus model of PCK (Carlson et al., 2020) to discuss how individual pre-service teachers (PSTs) develop their own personal PCK (pPCK), and how this knowledge is transformed into enacted PCK (ePCK) (in this case, science teaching). Knowledge of how PSTs think and teach is useful for improving teacher education programs that provide PSTs with coherent opportunities for professional development. The field of research on teacher knowledge requires long-term studies that explore how PCK enables high-quality instruction (Alonzo et al., 2020; Sorge, Kröger, et al., 2019; Sorge, Stender, et al., 2019; van Driel et al., 2014). Further, there is a need to study how PSTs develop PCK (Kaya, 2009), particularly in relation to their learning experiences during teacher education (Coetzee et al., 2020). Existing research on school practica is dominated by PSTs' self-reports (Lawson et al., 2015; Wilson et al., 2001). In addition, existing studies of PCK related to classroom teaching are focused on teachers' thinking about instruction (reflection-on-action) rather than the actual knowledge being played out in the classroom (reflection-in-action) (Kirschner et al., 2015; van Driel et al., 2014).

By investigating PSTs' translation of knowledge into instruction, my research sheds light on the relationship between theory and practice. Within teacher education programs, knowledge and practice components are usually separated (Wilson et al., 2001), particularly in the setting of school practica (Juhler, 2017). This issue is particularly relevant in Norway (Finne et al., 2014), where little cohesion among program components leads teacher education to have weak effects on the practices of new teachers (Hammerness, 2013). As a result, teachers are given the challenging task of translating theories about teaching into classroom instruction. Typically, they start working on this challenge when they enter classrooms in school practica (Allsopp et al., 2006; Grossman et al., 2009). Thus, combining theory and practice is of specific relevance for school practice (Juhler, 2017).

Shulman (1987) described pedagogical reasoning and action as the core of teaching. Three phases characterize teaching (Alonzo et al., 2020): planning, teaching, and reflection. Each phase includes theory applied in practice through pedagogical reasoning. Teachers' thinking during planning and reflection may be characterized as reflection-on-action. Reflection-in-action, in contrast, characterizes teachers' decision-making during classroom teaching (Henderson & Tallman, 2006; Schön, 1992). Although reflection-in-action is more complicated to research, the teaching phase is particularly critical to understand in order to improve education.

Park (2019) encouraged studies of the different levels of pedagogical reasoning based on science PCK. Focusing on PSTs' PCK in research is a particularly useful way of combining the theory and practice of science teachers (Juhler, 2017). By examining classroom practice and reflection-in-action, I help to build a reliable and valid understanding of how theory (in the form of science PCK) is transformed into practice (in the form of science instruction).

The project was initiated partly to evaluate the science part of a new teacher education program. The studied PSTs were in the first cohort of a new national five-year master's degree program in Norway, which provided teacher education applicable to grades 5–10 (UiT The Arctic University of Norway, 2016). This program allows students to specialize in a few teaching subjects, and it aims at cohesion between the components of the program. Instead of including separate courses for science content and methods, which is the international standard (Etkina, 2010; Fones et al., 1999; Kind, 2019), the new program combines CK and PCK in specialized content courses.

Whether and how specialized science courses impact classroom teaching and PSTs' professional development remains a largely unexplored topic. However, in a recent paper to which I contributed (Olufsen et al., 2021), we used mixed methods to investigate the effects of specialized science courses in the setting of school practica. Reports from PSTs and their mentor teachers indicated that specialized science courses had a positive impact on science teaching in this setting.

In this thesis, I use evidence from two research approaches to understand how pPCK is enacted in science instruction. Video recordings of PSTs' classroom practice were a critical data source, as they showed the PSTs' actions in the classroom. The participating PSTs' science teaching practices were described and related to their PCK. Further, the video recordings were used in video stimulated recall interviews (SRIs) to prompt PSTs to share their reflection-in-action. With this data, I investigated the PSTs' instructional decisions and reasoning from their own recent teaching. Thereby, I accessed their capacity to reason (i.e., knowing why they did what they did) as well as some of the knowledge they did not utilize in the lessons, or their pPCK (Chan & Hume, 2019). Together, the video and SRI approaches contributed to fulfilling the purpose of this thesis.

1.2 Purpose and overarching research questions

The purpose of this thesis is to describe knowledge exchanges between collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK), especially PSTs' ePCK in the context of school practica. To fulfill this purpose, I answered two overarching research questions: (1) "How do pre-service science teachers enact their first pieces of professional knowledge, especially PCK, in school practica?" and (2) "How do PSTs develop pPCK, and how is this knowledge transformed into ePCK during science teaching?" These questions were answered through a long-term study of six PSTs in their first year of a teacher education program and five PSTs in the third year of a program. All their science instruction in school practica during these years were videotaped. The knowledge and skills they used to teach science were examined as a case.

1.3 Structure of the thesis

This thesis is written in accordance with standards for PhD dissertations (UiT The Arctic University of Norway, 2019; Universitets- og høgskolerådet, 2018). The cover article you now read presents three research papers in a unified perspective. The papers are inserted in the latter part of the thesis. The current section outlines the components of the cover article.

When investigating teachers' knowledge and practices, it is necessary to clarify which theories of teacher knowledge and quality instruction are used as a starting point. In chapter 2, I present PCK as theoretical framework for teacher knowledge and overview existing knowledge about science teachers' PCK development as PSTs' PCK. Next, I discuss the connection between knowledge and classroom teaching. Based on this connection, particularly the connection from PCK to teaching, I describe a framework for instructional quality. Finally, I review research on PSTs' science teaching practices.

In chapter 3, I explain why video recordings and SRIs are suitable for addressing the overarching research questions. First, I present the overall research design. Second, I describe the context and participants of the project. I also present the structure and characteristics of the teacher education program under study. Third, I present and discuss the research methods in light of the overarching project design. Fourth, I discuss ethical considerations and quality aspects of my research.

In chapter 4, I describe the results of the three papers. I connect them to the overarching research questions and synthesize their findings using the refined consensus model of PCK.

In chapter 5, I discuss the results of the three papers in order to build rich descriptions of how PCK is enacted during classroom teaching in school practica. The chapter focuses on how the papers extend existing research on PSTs' knowledge and skills for teaching. Based on the theoretical background, I discuss how science PCK develops in the setting of initial teacher education in order to help reduce the gap between theory and practice in teacher education programs. Finally, I discuss the limitations of the project, draw conclusions, and discuss the implications for teacher education.

2 Theoretical background

In this chapter, I discuss the two theoretical frameworks I applied: pedagogical content knowledge (PCK) and instructional quality. Figure 1 illustrates the different forms of PCK and the two main approaches to determining science teachers' PCK: self-reports and performance in teaching tasks. In this project, I used the second approach. I investigated pre-service teachers' (PSTs) performance in teaching tasks in order to investigate what they know, what they do, and the reasoning for their actions. To closely connect my research to classroom teaching, I investigated PSTs' actions in the classroom, articulation of decisions during instruction, and reflections on teaching.

The PCK framework serves as base for my investigation of PSTs' knowledge, their enacted knowledge, and their capacity to reason (fig. 1). Therefore, in section 2.1, I explore how PCK develops, and I review research on PSTs' science PCK. In section 2.2, I explain how classroom teaching is professional knowledge in action (i.e., ePCK). In section 2.3, I present the framework on instructional quality. In the fourth part of the theoretical background (2.4), I explore my views on learning in relation to the project.

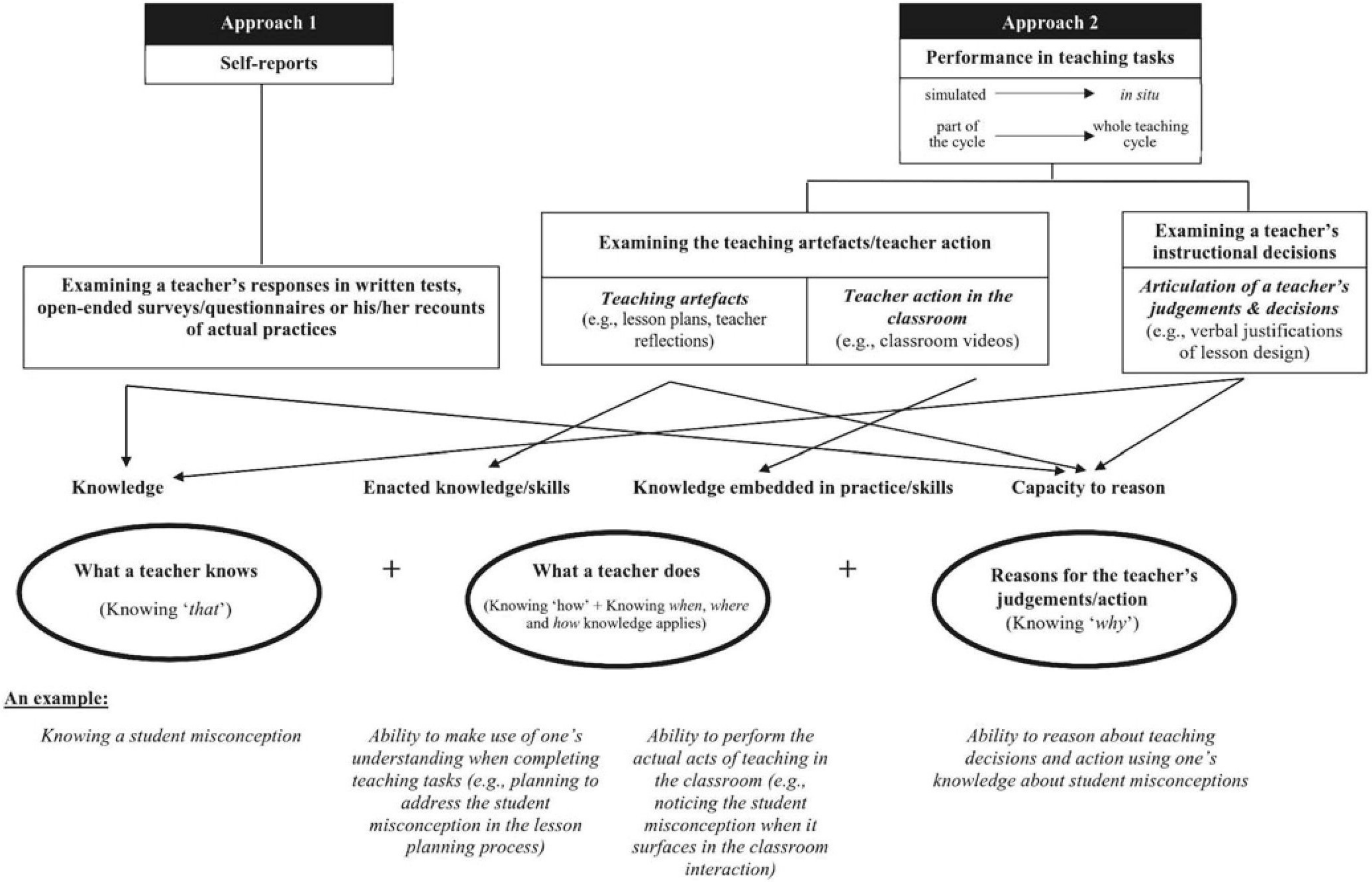

Figure 1: Approaches for determining science teachers' PCK and their relationship with different forms of PCK. Reprinted with permission from Springer Nature, Repositioning pedagogical content knowledge in teachers' knowledge for teaching science, by A. Hume, R. Cooper, & A. Borowski (Eds.) COPYRIGHT 2020

2.1 Knowledge for teaching

In the following, I first overview teachers' professional knowledge bases (2.1.1). Second, I present the two models that are applied to examine PCK and argue for my focus on selected parts of the models (2.1.2). Third, I discuss researchers' views on PCK development (2.1.3). Fourth, I present research on PCK development and the need for further research (2.1.4). Finally, I provide a short review of the field of research on PSTs' science PCK (2.1.5).

2.1.1 Overview of teachers' professional knowledge

Content knowledge (CK), general pedagogical knowledge (PK), context knowledge, and PCK are professional knowledge bases for teachers' classroom work (Fischer et al., 2012; Gess-Newsome, 1999; Grossman, 1990; Shulman, 1987).

- CK refers to teachers' knowledge of the facts, concepts, and practices of a scientific discipline (Nixon et al., 2017), as well as how knowledge is structured in the discipline (Schwab, 1964; Shulman, 1986).
- General PK is applicable across subjects, and it includes knowledge of learning and learners, general principles of instruction, and classroom management (Grossman, 1990). "General PK" and "PK" are used interchangeably in the current thesis.
- Context knowledge is what teachers must know to adapt to students in a specific school or community. This includes knowledge about the educational climate, classroom environment, and student attributes (Carlson et al., 2020).

One should note that the understanding of PK described above differs from the continental European understanding, which is relevant in Norway. Here, pedagogy (*pedagogikk*) includes knowledge of teaching, upbringing, socialization, and educational knowledge at different levels of society (Imsen, 2011). The concept of *pedagogy* used in the current thesis captures general knowledge of teaching that is bound to the classroom setting (Grossman, 1990). The other aspects of pedagogy are covered by context knowledge.

Figure 2: Teachers' knowledge bases. Based on Grossman (1990).

PCK is subject-specific knowledge that enables teachers to teach specific content well (Fischer et al., 2012; Grossman, 1990). Such knowledge is based on PK, CK, and context knowledge (Fig. 2). PCK was first introduced by Lee Shulman (1986, 1987) as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). Later, PCK was developed for various subjects (e.g., Ball et al., 2008; Grossman, 1990; Magnusson et al., 1999). Below, I will present two models that elaborate on the features of PCK. The first connects different realms of PCK, from shared knowledge to the knowledge held and enacted by an individual teacher. The second distinguishes between the concrete components of PCK that can be identified in research.

2.1.2 Pedagogical content knowledge

PCK has been found to be a useful framework for evaluating the knowledge required to teach science (Chan & Hume, 2019; Hermansen, 2018; Kind, 2009b). In addition, it is highly related to quality instruction that results in student learning (Fauth et al., 2019; OECD, 2005; Sadler et al., 2013; Wilson et al., 2001). In this thesis, PCK serves as the conceptual framework for teacher knowledge. In line with Baxter and Lederman (1999), I view PCK as "both an external and internal construct, as it is constituted by what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (p. 158). These aspects are integrated in the refined consensus model (fig. 3), which presents three realms of the knowledge domain—enacted PCK (ePCK), personal PCK (pPCK), and collective PCK (cPCK)—and situates PCK within knowledge bases (Carlson et al., 2020).

ePCK involves the knowledge and skills used by a teacher in a specific teaching situation, such as pedagogical reasoning during planning, teaching, and reflection upon lessons (Carlson et al., 2020). ePCK brings together teachers' knowledge, instruction, and students' outcomes.

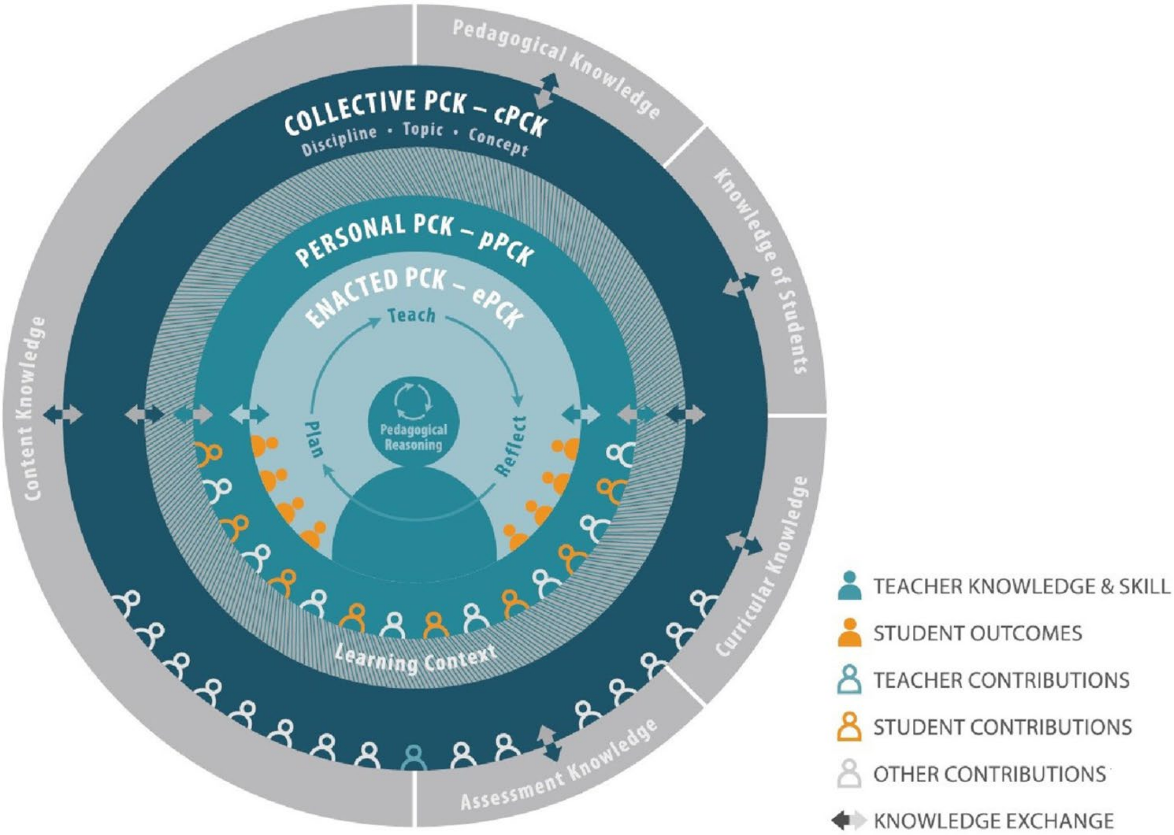

Figure 3: The refined consensus model. Reprinted with permission from Springer Nature, Repositioning pedagogical content knowledge in teachers' knowledge for teaching science, by A. Hume, R. Cooper, & A. Borowski (Eds.) COPYRIGHT 2020

In the refined consensus model, the layers are connected by two-way arrows. These represent knowledge exchange, which is amplified or filtered through teachers' attitudes and beliefs about, for example, students, the nature of science knowledge, or the role of the teacher. The innermost exchange takes place when ePCK is carved out from pPCK, or the whole of a teacher's knowledge base for teaching science topics for particular students in particular learning contexts.

The learning context separates pPCK from cPCK, the most public realm. This context situates science teaching and learning in space and time. The three contextual levels are the broad educational climate, a specific classroom learning environment, and individual student attributes. The context amplifies and filters the teacher's actions. For example, a national curriculum may encourage a teacher to use inquiry teaching, but a lack of equipment or students' lack of experience with laboratory work may prevent a teacher from doing specific experiments.

cPCK is the amalgam of the education community's (somewhat generic) knowledge for teaching particular science topics. cPCK is located within various groups, from teachers working in a professional learning community to canonical PCK that is accessible in the research literature. Thus, in the realm of cPCK, a teacher may represent one of many contributors.

The outermost circle of the refined consensus model represents professional knowledge bases that inform PCK: CK, PK, knowledge of students, curricular knowledge, and assessment knowledge. The size of the CK sector indicates its special importance for the development of PCK. The closer one gets to the center of the refined consensus model, the more likely it is that PCK exists in a tacit form. For example, while cPCK is likely to appear in conversations between educators or in written form, pPCK often appears in teachers' reflection upon practice, and ePCK is the tacit knowledge that drives teachers' instructional decisions (Alonzo et al., 2020).

The authors of *The refined consensus model of pedagogical content knowledge in science education* chapter (Carlson et al., 2020), did not intend to replace prior models of PCK. As it lacks descriptions of concrete components of science PCK, I also use a model developed by Magnusson et al. (1999) (fig. 4), hereafter called the Magnusson model.

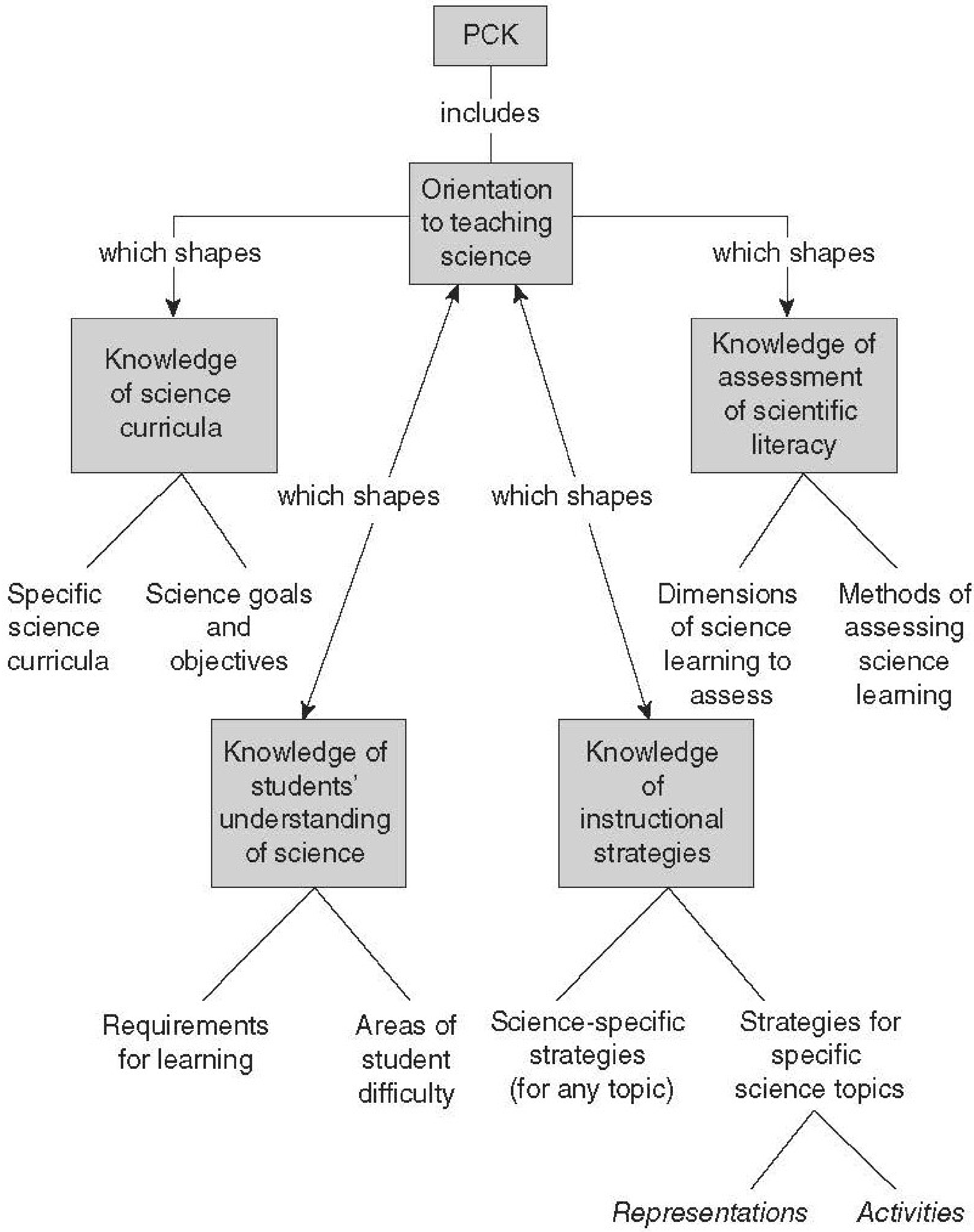

Figure 4: Magnusson PCK model as represented in A. Berry, P. Friedrichsen, & J. Loughran (Eds.) (2015). Reprinted with permission from Routledge. COPYRIGHT 2015

It conceptualizes science PCK as consisting of four components: knowledge of science curricula, knowledge of students' understanding of science, knowledge of instructional strategies, and knowledge of assessment of scientific literacy. Each of the components includes sub-groups of knowledge. A fifth component of the model, orientation to teaching science, influences each of these four components.

The orientation component has been interpreted in various ways (Friedrichsen et al., 2011). In the refined consensus model, it is represented by the knowledge exchange arrows, which amplify or filter knowledge exchange. Although teachers do not separate their knowledge into silos, as suggested by a theoretical model (Friedrichsen, 2015), the Magnusson model has proven useful in research (Friedrichsen & Berry, 2015). In the refined consensus model, the four components are included in each of the three realms of PCK, and they are related to knowledge bases for PCK in the outermost circle (Carlson et al., 2020).

Some researchers view PCK as topic-specific (e.g., knowledge of how to teach photosynthesis) (Gess-Newsome, 2015; Mavhunga, 2020), while others view PCK as existing at the discipline level (e.g., how to teach argumentation in science courses) (Davis & Krajcik, 2005). In the refined consensus model, each realm of PCK can be either topic- or discipline-level. In the current project, I examined both topic-specific and science-specific PCK. Although the Magnusson model is focused on topic-specific PCK, its categories may also be used to examine science-specific PCK (Friedrichsen et al., 2009).

It is the totality of all components that makes PCK such a powerful conceptualization (Chan & Hume, 2019). However, two components are of particular importance to draw upon during lesson planning and enactment: knowledge of students' understanding of science and knowledge of instructional strategies (Chan & Hume, 2019; Kind, 2009b). Simultaneous use of these components is a critical step in PCK development (Akin & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012). Thus, in this thesis, I focus on these two components and the integration of them. This integration involves knowledge of how students' learning processes impact the sequencing of instruction (Brown, 2008). My choice of focus sets aside other integrations, but a strategic choice of focus in PCK research is necessary (Schneider & Plasman, 2011).

PCK is related to *didaktik,* a concept of German origin. *Didaktik* covers various particularities connected to education such as how to form a subject from content knowledge, the relationship between content, its academic background and history, and questions of value related to education. PCK is a subset of *didaktik* concentrated on classroom teaching, that is oriented more towards research (Berry et al., 2016; Kansanen, 2009). In this thesis, the English term "subject-didactics" is used to describe the particular *didaktik* for science. Then, it is important to note that *didaktik* does not refer to a didactic orientation to teaching (Magnusson et al., 1999), in which students are seen as blank slates to be filled by the teacher.

2.1.3 How science pedagogical content knowledge develops

Supported by context knowledge, science CK and PK contribute to the development of science PCK (Kind & Chan, 2019; van Driel et al., 2014). This relationship can be understood in two different ways. First, when viewed as integrative, science PCK may be described as a chemical mixture of science CK, PK, and context knowledge (Gess-Newsome, 1999; Kind, 2019). A teacher needs to develop these knowledge bases alongside each other, and they intersect in classroom teaching. According to the second view, when supported by context knowledge, science CK and PK can transform into PCK. In this transformative view, the formation of PCK is more like a chemical reaction forming a new compound (Gess-Newsome, 1999; Kind, 2019). The transformative view is most visible in the refined consensus model, as PCK is depicted as transformed from the knowledge base. However, the integrative view may also be illustrated by knowledge expressed in teacher actions (i.e., ePCK). Both views may be useful for describing the development of PCK, and Kind (2015) even concluded that the distinction was irrelevant.

The goal for an individual teacher is to develop a solid pPCK to teach relevant topics. For this, they draw on (a) knowledge about teaching located across a continuum of groups, from peers or colleagues to canonical PCK accessible in research literature (i.e., cPCK outside the teacher's specific context), and (b) teaching experience from within the context of a classroom (i.e., ePCK) (Sorge, Stender, et al., 2019) (see the refined consensus model in section 2.1.2). Below, I discuss two sources of teachers' pPCK from the cPCK realm, as well as teaching experience from the ePCK realm.

First, personal learning experiences in K-13 schools are the initial source of teachers' PCK (Brown, 2008; Coetzee et al., 2020; Friedrichsen et al., 2009; Grossman, 1990). These experiences from a teacher's own schooling shape their CK, PK, and certain components of PCK. Memories of which goals their own teachers taught informs knowledge of science curricula, and experience with learning from their own schooling informs knowledge of students' understanding (Grossman, 1990). This is particularly true for learning difficulties (Jong et al., 2005; Kellner et al., 2011) and what to expect from students (Grossman, 1990). Lastly, memories from learning specific content are connected to how the content was taught, thereby informing knowledge of instructional strategies (Grossman, 1990).

Although prior learning experiences are a substantial source of PCK, they are often seen as a challenge to educational reform (Grossman, 1990). Labelled "apprenticeship of observation," prior learning experiences have been found to conserve teaching practices and weaken the effects of teacher education (Juhler, 2017; Lortie, 1975; Sorge, Kröger, et al., 2019). In other words, there is a risk that new teachers will imitate their own teachers instead of using reformed teaching practices (Brown et al., 2013; Grossman, 1990). However, other researchers have argued that this view is too deterministic, highlighting that specific memories from teaching and learning situations are less challenging than the general milieu of teaching experienced during years of schooling (Smagorinsky & Barnes, 2014).

A second source of PCK development is teacher education courses. These are important as a starting point for targeted PCK development (Berry et al., 2016; Coetzee et al., 2020; Friedrichsen et al., 2009; Kind & Chan, 2019). In their cross-national study of predictors of PCK, Park et al. (2020) found teaching certification to be closely related to higher PCK scores. Coursework is particularly useful when PCK is used as an explicit framework (Daehler et al., 2015; Etkina, 2010; Nilsson & Loughran, 2012; van Driel et al., 2002), specifically to understand students' ideas and how to build on students' existing knowledge (Etkina, 2010). However, some studies have found that pre-service programs have a minimal impact on PCK development (e.g. Lee et al., 2007). For example, Brown et al. (2013) found that PSTs continue providing teacher-centered instruction after learning about student-centered strategies in a teacher education program. Research on the structure of teacher education programs indicates that intertwining science learning with science teaching is beneficial for growth in science PCK (Daehler et al., 2015). As an example, repeated exposure to and implementation of student-centered instruction have resulted in new student-focused teaching habits among PSTs (Etkina, 2015).

Third, teaching experience is a central source of PCK development (Grossman, 1990; Großschedl et al., 2015; Nilsson & Loughran, 2012; Sorge, Stender, et al., 2019). Thus, school practica have the potential to serve as an arena for PCK development. In classroom teaching, PSTs have the opportunity to explore the dialectics between theory and practice (Lawson et al., 2015). Additionally, "learning is enhanced when teacher candidates are provided with multiple opportunities to apply what they have learned in meaningful contexts" (Allsopp et al., 2006, p. 20). In the classroom setting, teachers benefit from observing instruction (Sorge, Kröger, et al., 2019) and teaching their own lessons in which they can experience students' behavior and questioning (van Driel et al., 2002). Classroom experience has been found to result in the development of knowledge about students' thinking (Nilsson & Loughran, 2012; Park et al., 2020), specific learning difficulties (Jong et al., 2005; van Driel et al., 2014; van Driel et al., 2002), and conceptual teaching strategies (Coetzee et al., 2020).

Although few studies have been conducted on PCK in the setting of teaching practice (van Driel et al., 2014), the available studies have provided useful insights. For example, reflection seems to be critical for developing PCK from teaching experience. In their study of PSTs in a teacher education program, Wongsopawiro et al. (2017) found that teachers who reflected on students' learning alongside their classroom instruction developed PCK in support of instructional methods that promote students' learning. Outside teacher education programs and without facilitated reflection on teaching, research indicates that teaching experience does not result in the development of science PCK (Friedrichsen et al., 2009).

2.1.4 Research on the development of science pedagogical content knowledge

In the current section, I review empirical research on the development of science PCK and identify which areas of the field remain unexplored. Research on this topic is challenging. First, within in the realms of ePCK and (sometimes) pPCK, science PCK is tacit knowledge (Alonzo et al., 2020). In other words, it is seldom articulated by teachers, and therefore, it is difficult for researchers to access. Second, its relationships to CK and PK can be understood in different ways (Kind, 2019), complicating research on its development. Third, it is difficult to disentangle the impacts of personal experience, coursework, and other factors (Wilson et al., 2001).

Although different lines of research have advanced the understanding of PCK development, there is a need for more research. For example, much of the existing research on school practica has been based on PSTs' self-reports (Lawson et al., 2015; Wilson et al., 2001). Although self-reported conceptions are closely connected to teacher and student outcomes, they are prone to bias, misperception, and lack of memory (Ronfeldt & Reininger, 2012). Thus, there is a need for valid and reliable investigations of the development of science PCK in the context of school practica.

Teachers may be aware of what is good teaching, but lack the ability to implement it (Kind, 2009b). Sorge, Stender, et al. (2019) specifically called for PCK studies related to the quality of learning opportunities. In addition, van Driel et al. (2014) stated that "questions related to what PSTs do with their PCK and how practice interacts with PCK so far remain largely unexplored" (p. 859). Recently, Alonzo et al. (2020) identified a similar gap regarding studies on the realm of ePCK.

The tacit nature of PCK makes it challenging to capture in classrooms. Therefore, it is useful that teacher actions are closely related to teacher knowledge (Fauth et al., 2019) and may serve as an alternative data source. However, other research has indicated that this relationship is highly variable (Baxter & Lederman, 1999). Thus, classroom observations alone are not sufficient to elicit teachers' PCK.

Studies of teachers' lesson planning and reflection have provided valuable insights into the development of science PCK (e.g., Juhler, 2017). However, researchers need to include teachers' thoughts about their own actions in the classroom in order to understand their exchange of pPCK into ePCK (Alonzo et al., 2020; Kind, 2019). van Driel et al. (2014) called for studies that relate classroom interactions from science lessons to teacher knowledge, suggesting stimulated recall interview (SRI) studies that explore teachers' reflections on teaching practice. Such research builds on the assumption that teachers' cognition is reflected in their teaching practice (Chan & Hume, 2019; van Driel et al., 2014). Sub-studies 2 and 3 in the current project are situated in this line of research, adding to existing studies that have used SRIs to examine instructional decisions (e.g., Brown, 2008; Nilsson, 2008; Schepens et al., 2007; van Driel et al., 2002).

Lastly, researchers in the field have recognized a need for research focused on teachers' development of integrations among PCK components to make a topic understandable for students (Akin & Uzuntiryaki-Kondakci, 2018; Aydin et al., 2015; Chan & Hume, 2019). The current study adds to a line of research that responds to this need by further developing the PCK map approach proposed by Park and Chen (2012).

2.1.5 Research on pre-service teachers' science pedagogical content knowledge

Available research on PSTs indicates that they usually have limited PCK for science (Kind, 2009b; Schneider & Plasman, 2011; van Driel et al., 2002). They may have problems understanding what students find difficult (i.e., knowledge of students' understanding of science) (Halim & Meerah, 2002) and how to make abstract concepts accessible for students (i.e., knowledge of instructional strategies) (Jong et al., 2005; Kind, 2009b). Poor PCK may relate to lack of CK in the topics at hand (Käpylä et al., 2009; van Driel et al., 2014). In a study aiming to explore PSTs' PCK for teaching heritable variation, participants planned lessons based on PK, as they lacked PCK in the topic (Friedrichsen et al., 2009). In a recent Norwegian PCK study, PSTs in their third year of a teacher education program focused mainly on concerns related to general management and survival in the role of teacher (Juhler, 2017).

Some studies have identified PSTs' PCK related to student difficulties (Jong et al., 2005; Kellner et al., 2011), and reflections on instructional strategies in science (Sjöberg & Nyberg, 2020). Also, Kind (2019) found that a third of the participating PSTs had PCK relevant to the topic at hand. However, the PCK was incomplete and led to student misconceptions.

PSTs seldom draw on multiple PCK components simultaneously, referred to as PCK integration (Akin & Uzuntiryaki-Kondakci, 2018; Aydin et al., 2015; Juhler, 2017; Kind, 2009b; Sickel & Friedrichsen, 2018). However, some studies show that PSTs can develop integrated PCK over time (Brown et al., 2013; Sjöberg & Nyberg, 2020) or through a PCK intervention in teacher education (Mavhunga, 2020). By analyzing Content Representations and video annotations made by science PSTs, Nilsson and Karlsson (2019) showed how these tools scaffolded reflections and integrations of PCK components.

Little research has focused on ePCK (Alonzo et al., 2020). Park (2019) identified a need for studies on how PCK manifests in classroom practice with the use of SRIs. In one recent study, Coetzee et al. (2020) showed three PSTs' ability to enact components of PCK to teach electromagnetism, although they did so at different levels for different ideas related to the topic.

A main purpose of this thesis was to describe the enactment of PCK. Following suggestions mentioned in the preceding sections, I studied the integration of knowledge of students' understanding of science and knowledge of instructional strategies in the realm of ePCK. Further, I have traced experiences from teacher education courses as one source of PCK development.

2.2 Classroom practice – knowledge in action

In this section, I explain how PCK relates to classroom teaching including how the refined consensus model locates classroom teaching within the realm of ePCK.

Inspired by Shulman (1986), I see quality teaching as not just acts or behavior, but self-conscious enactment of knowledge in complex classroom situations. This connection between knowledge and teaching is reflected in the refined consensus model, where ePCK refers to the subset of pPCK that is used in a particular teaching situation. Its location in the center of the model (fig. 3), together with student outcomes, represents that classroom instruction and student learning are the end goals of PCK development (Carlson et al., 2020).

Alonzo et al. (2020) explained that PCK is enacted in three phases: planning, teaching, and reflection. At the macro level, a plan–teach–reflect cycle focuses on one unit of instruction. For example, teachers draw on their pPCK during lesson planning, teaching, and reflection on the lessons. The micro level of the same cycle occurs during the teaching phase of instruction. Indeed, each instructional move in the teach phase includes a micro cycle of pedagogical reasoning. For example, an interaction with a student may constitute an instructional move. The move may be introduced by a student sharing a question, to which the teacher responds using reflection-in-action (plan). The response is given (teach) and the interaction is evaluated (reflect) within the teacher's reflection-in-action. ePCK is utilized in the multiple micro cycles that arise during a lesson (Alonzo et al., 2020).

The relationship between ePCK and pPCK is two-way. As described above, based on Alonzo et al. (2020), instruction is characterized by the continuous process of pPCK transforming into ePCK. At the same time, teachers develop pPCK from pedagogical reasoning. This pPCK is most often tacit, which means that it is not articulated by the teacher. For example, attention to a specific student misconception may lead a teacher's future lessons to take that misconception into account. However, it could be made explicit when, for example, a teacher reflects upon a student misconception in a lesson and thinks through possible strategies to address that misconception in future lessons. It should be noted that although multiple studies have found teaching experience to be a major source of PCK (Grossman, 1990; Nilsson & Loughran, 2012), the ePCK/pPCK framework has contributed to mixed results regarding whether ePCK has an impact on pPCK (Kulgemeyer et al., 2020). In the current project, the development of pPCK from ePCK is not a main focus.

By locating classroom practice as the central component in the refined consensus model, the authors who developed it enable a coherent view of science classroom teaching in theory and practice (Carlson et al., 2020). Argyris and Schön (1974) define theories that are expressed through action as *theories in use.* When actions are based on theory, the actions carry theory with them. This is implicit in actions and can be derived from practice (Argyris & Schön, 1974; Pettersen, 2005). In this way, *theories in use* can contribute to explaining the relationship between a teacher's knowledge and teaching practice. One way that PCK has contributed to education is by addressing an existing separation of theory and practice in teacher education (Juhler, 2017; Shulman, 2015). By treating classroom practice as knowledge in action, the current thesis builds on this important point with PCK and contributes to the understanding of how PSTs use their knowledge for teaching.

2.3 Instructional quality

To investigate PCK embedded in teaching practice, I needed a theoretical framework on instructional quality connected to PCK. A number of studies have demonstrated a close connection between PCK and instructional quality, including those based on statistical analyses (Fauth et al., 2019; Kulgemeyer et al., 2020) and qualitative methods (Coetzee et al., 2020; Mavhunga & van der Merwe, 2020).

I focused my investigations of enacted PCK on knowledge of students' understanding of science integrated with knowledge of instructional strategies. Park et al. (2011) found these components and the integration of them to be highly connected to reform-oriented teaching. This specific kind of quality teaching includes emphasis on student-centered and inquiry-based teaching (Anderson et al., 1994; Sawada et al., 2002). A reform-oriented approach aligns with constructivist learning theories due to its focus on students as active learners rather than the teacher as a supplier of information (Anderson et al., 1994). Adding to the Park et al. (2011) paper, other researchers has elaborated on how the central PCK components in combination lead to reform-oriented instruction in the forms of student-centered teaching (Alonzo et al., 2012) and inquiry-based teaching with focus on argumentation (Suh & Park, 2017).

Together, the four dimensions of instructional quality presented below include critical dimensions of instructional quality in connection to PCK. I used three central dimensions of instructional quality from a framework proposed by Klette et al. (2017): cognitive activation, discourse features, and instructional clarity. Further, I included scientific inquiry, representing a particularly important dimension of the subject of science (Crawford, 2014). The four dimensions of instructional quality are described and grounded in the literature below, as also presented in paper 1.

2.3.1 Cognitive activation

The dimension of cognitive activation concerns whether a teacher engages students in higher-level thinking (Klette et al., 2017). Science education research has emphasized the need for to support students in changing their conceptualization of science, making cognitive activation an important feature of science instruction (Fauth et al., 2019). According to some research, cognitive activation results in higher student achievement (Fauth et al., 2019; Förtsch et al., 2016; Neumann et al., 2012).

When providing cognitively activating instruction, teachers engage students in reflection, analysis, and comparison of ideas. In less cognitive-activating instruction, students are provided with tasks that merely require them to repeat and recall information (Lipowsky et al., 2009). Cognitive activation also increases when students' prior knowledge is activated (Grossman et al., 2013), and they are explicitly asked to reflect on their own learning (Lipowsky et al., 2009). In short, cognitive-activating instruction challenges students to do more intellectual work (Klette et al., 2017).

Teachers with well-developed PCK are better able to give cognitively activating instruction (Fauth et al., 2019). They use knowledge of students' misconceptions and difficulties with the science content to provide intellectual challenging questions (Ergönenç et al., 2014; Förtsch et al., 2016).

2.3.2 Discourse features

The dimension of discourse features captures discussion formats as well as the quality of responses provided to students. In science it is important to allow students to argue and justify their ideas. Through this, dialogic classroom discourse eventually increases students' science competency (Neumann et al., 2012; Scott et al., 2006; Treagust & Tsui, 2014).

At lower levels, discourse might follow the initiation–response–evaluation format, in which the teacher closes the discussion without prompting further student responses (Scott et al., 2006). At higher levels, discourse is dialogic in format, with the teacher offering prompts for further elaboration and extending dialogues between the teacher and students or between students (Scott et al., 2006).

The relationship between PCK and dialogic discourse is similar to that with cognitive activation. To engage students in discussions about science ideas, teachers need to know these ideas (knowledge of students' understanding of science) and find approaches to initiate meaningful discussions (knowledge of instructional strategies).

2.3.3 Instructional clarity

Instructional clarity includes the clarity and explicitness of the learning goals, presented content, and feedback on students' work or ideas. It relies upon representations, explanations, and precise use of scientific language (Klette et al., 2017).

This dimension most explicitly captures the need for teachers to communicate knowledge to students. Understood as interactions between teachers and students rather than transmissive teaching, explanations are a core element of teaching (Kulgemeyer et al., 2020). Research has documented the usefulness of instructional representations in science teaching to improve students' cognitive and affective outcomes (Treagust & Tsui, 2014; Tytler et al., 2013). In particular, structured presentations have been found to impact student achievement positively (Neumann et al., 2012). Constructive feedback is an important aspect of supporting students' construction of knowledge, sensemaking, and conceptual change (Fauth et al., 2019; Grossman et al., 2013).

Finally, instructional clarity in science emphasizes the need for real-life experience with science phenomena, as in practical activities. Students engaged in practical activities are known to have increased potential for learning science, especially if the practical activities involve working in groups and focus on developing scientific ideas (Abrahams & Millar, 2008; Hofstein & Kind, 2012).

Central in science PCK are knowledge of what makes the content difficult, knowledge of specific misconceptions, and knowledge of instructional strategies with explanatory power (van Driel et al., 2014). Thus, instructional clarity is closely connected to PCK.

2.3.4 Scientific inquiry

The scientific inquiry dimension concerns the application and quality of inquiry teaching. It is related to scientific reasoning, a feature of quality instruction which focuses on inductive and deductive reasoning (Treagust & Tsui, 2014). Postman and Weingartner (1969) made the case that students need to develop the art and science of inquiring rather than remembering explanations from a teacher or a book.

Three important phases have been emphasized by researchers of scientific inquiry: ask a question and plan an investigation, carry out the investigation and organize data, and reason based on the findings to draw conclusions (Bybee et al., 2006; Knain & Kolstø, 2019). Through scientific inquiry, students can achieve cognitive gains and increased interest in science (Crawford, 2014). Also, they can develop competence related to the nature of scientific knowledge (NOSK) (Lederman & Lederman, 2019).

The central components of PCK and integration of them has been found to correlate with reform-oriented inquiry teaching (Park et al., 2011). Supported by change in orientation to teaching science, teachers' expanded knowledge of students' understanding of a science concept may facilitate teachers' use of inquiry (Suh & Park, 2017). It should be noted that scientific inquiry does not focus on the ability of teachers to clearly communicate science content with students, but how to lead them into investigating their science-related questions in a fruitful way.

2.3.5 Research on pre-service teachers' instructional quality

Although teaching activities form a major component of school practica in teacher education programs, studies of them are limited in number and, to some degree, characterized by reliance on self-reports (Cohen et al., 2013; Jenset, 2018; Lawson et al., 2015; Wilson et al., 2001). Existing studies indicate that beginner pre-service teachers (PSTs) focus on themselves rather than students and their learning (Juhler, 2017; Kagan, 1992; Körkkö et al., 2016). Classroom management is a common concern among PSTs, leading them to design activities that give them more control (Zembal-Saul et al., 2002). When PSTs assume the role of a transmitter of information, their ability to consider students and their learning is limited (Brown et al., 2013; Geddis & Roberts, 1998).

Some studies have directly investigated beginner PSTs' ability to carry out student-centered teaching. In such teaching, prior knowledge is taken into account and students are active participants in their learning rather than passive recipients of information (Baeten et al., 2013). In a small case study, Mellado (1998) found that participating PSTs viewed the class more as a group than as different individuals. Further, they were incapable of transferring much of their knowledge about science teaching into the classroom. None of them were able to systematically address individual students' ideas or monitor their learning individually (Mellado, 1998). Similarly, a study of 20 Finnish PSTs performed by Ratinen et al. (2015) showed that participants lacked the ability to challenge students' thinking. Even though they had planned to teach dialogically, the participating PSTs ignored students' pre-knowledge (Ratinen et al., 2015).

Later in teacher education programs and during internships in schools, teachers may still struggle to give quality instruction. Vagi et al. (2019) reported on a large observation study of 1,283 PSTs' development of quality teaching practices during school-based training in their senior year of teacher education. On average, the PSTs scored 2.4 on a seven-point scale, where a score of three indicated proficient teaching.

Scores increased throughout the year, although PSTs with high scores at the initial evaluation showed lower rates of improvement. In another study of 264 PSTs from 64 schools, van de Grift et al. (2014) found that the average PST was able to create a safe and stimulating learning climate, manage classrooms effectively, deliver clear instruction, and activate their students' learning. However, the PSTs had difficulties teaching learning strategies and adapting their teaching to address students' differences and learning needs.

However, some studies have found that PSTs can successfully carry out quality instruction. Based on their classroom observations, Thompson et al. (2013) found that 11 of 26 PSTs readily carried out teaching with their target indicators related to student-centered teaching. While university courses and mentors pressed for this kind of teaching, demands at practicum schools to cover content and keeping pace with colleagues hindered the other 15 PSTs to perform student-centered teaching. Temiz and Topcu (2013) studied the teaching practices of science and mathematics PSTs in their third year of an undergraduate program. The participants scored high on the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002), indicating success in carrying out teaching focused on students.

2.4 My views on learning

Three important dimensions of learning are content, incentive, and interaction. Below, I briefly overview these based on the work of Illeris (2012). Jean Piaget (1896–1980) described the content dimension as the nature of how humans learn through constructing an understanding of the world. The incentive dimension involves the mobilization of mental energy to drive this learning process, including motivations, emotions, and volition. The interaction dimension is based on the idea that learning is not the domain of individuals, but takes place in social interactions (Lev Vygotsky, 1896–1934). Interactional learning occurs in action, communication, and collaboration within the learning context, and use of language is a central means of knowledge construction. (Illeris, 2012)

My understanding of learning tends towards a constructivist position, as it is focused on content, although learning as interaction is certainly an important dimension. This view more or less extends to how I understand students' learning, PSTs' development of PCK, and the way I develop knowledge as a researcher.

Students mainly construct their knowledge rather than receiving it from the teacher. In Piagetian terms, they are maintaining an equilibrium between adding elements to existing knowledge schemes and changing the schemes in response to knowledge that does not fit into the current schemes. Therefore, teachers should treat students as active participants in their own learning processes. This is part of the basis for reform-oriented education, particularly student-centered (Anderson et al., 1994). At the same time, I acknowledge that students usually construct knowledge based on observable entities. For example, students learn about actual climate change, not merely an idea about climate change. Furthermore, the social aspect of learning is clearly important for student learning because scientific knowledge is discursive in nature and implies enculturation into science as a culture (Driver et al., 1994). This is represented in a focus on student–student interactions and participation in scientific practices or inquiry teaching in current science education reforms.

PSTs do not develop their PCK solely by reading books, but by exploring the act of teaching, identifying common learning difficulties faced by students for various topics (Jong et al., 2005), and negotiating the complexities of teaching practice with others (Park, 2019). In other words, PCK development can be understood from a constructivist view of teacher learning. From a Piagetian perspective, individual PSTs build unique collections of PCK due to their unique set of schemas and knowledge. Thus, PCK is idiosyncratic, as confirmed by empirical studies (Akin & Uzuntiryaki-Kondakci, 2018; Aydin & Boz, 2013).

I understand PCK mainly as mental representations organized and held by individual teachers (pPCK), and thus, as a cognitive aspect of teacher learning. From this perspective, the development of knowledge through a complex process that includes pedagogical reasoning is considered to be the core of teacher learning (Russ et al., 2016). I also see PCK as mental representations enacted by individual teachers (ePCK). My investigation of sources for PCK revealed that PSTs link their mental PCK representations to other persons and situations. Thus, teacher learning can be best explained from a situated and sociocultural perspective as changes in communication with communities (Russ et al., 2016).

I view my learning as a researcher as a product of my construction of knowledge and insights based on data. I see my research as a constructivist process centered around my use of observations, interviews, and theory. In building new knowledge, I seek to be true to actual actions, statements, and reflections by the participating PSTs. At the same time, I acknowledge that my positions and understandings impact the outcomes of the project. I selected the phenomena of study, area of focus, research questions, and methods, and I interpreted the findings. When suitable, my positions are explicitly discussed (see, for example, section 3.6.3, which concerns my role as a researcher).

3 Methodology

Inspired by Yin (2009), I used a case study approach for this project. I also based my approach on Shulman's (1986) paper, in which he proposed *case knowledge* as a central component of inquiries about teacher education. In my inquiry, a total of seven pre-service teachers (PSTs) were videotaped as they taught science in school practica over a timespan of three years. Shortly after the instruction, I probed their pedagogical reasoning through stimulated recall interviews (SRIs).

In this chapter, I explain the study design, present the context and participants, and discuss research methods as well as issues of quality and ethics.

3.1 Research design

The research was designed as a qualitative case study. I followed the participating PSTs with multiple approaches to gain complimentary pieces of knowledge about their pedagogical content knowledge (PCK) and practice. The case study approach was appropriate as I wanted to study the phenomenon in depth and within a real-world context. The case included seven participating PSTs. Six were studied in papers 1 and 2, and three were studied in paper 3. I studied the PSTs as embedded units in the same case, as they worked together in groups in school practica. I began by analyzing data at the level of individual PSTs but lumped them together as one case based on similarities. The method of a single case study with embedded units has been described by Yin (2009). The case was bound by the PSTs' science teaching in school practica during their first and third years in a teacher education program.

These seven PSTs were worth studying as they represented a variety of levels of science education and teaching experience. They were typical in age, having finished high school relatively recently, and most were available at several points in time for this long-term case study. Features of the context of school practicum were integrated into the case, as the PSTs planned science lessons together with peers and a mentor teacher.

Case studies are useful to answer both "how" questions and "why" questions (Yin, 2009). Thus, the case study approach is a god fit for my project, as I aim to address both how PCK and teaching come about, and "why" questions regarding sources of knowledge and practices.

Fig. 5 illustrates the phenomenon of PCK enacted in classrooms by a PST in the process of exchanging PCK into science instruction.

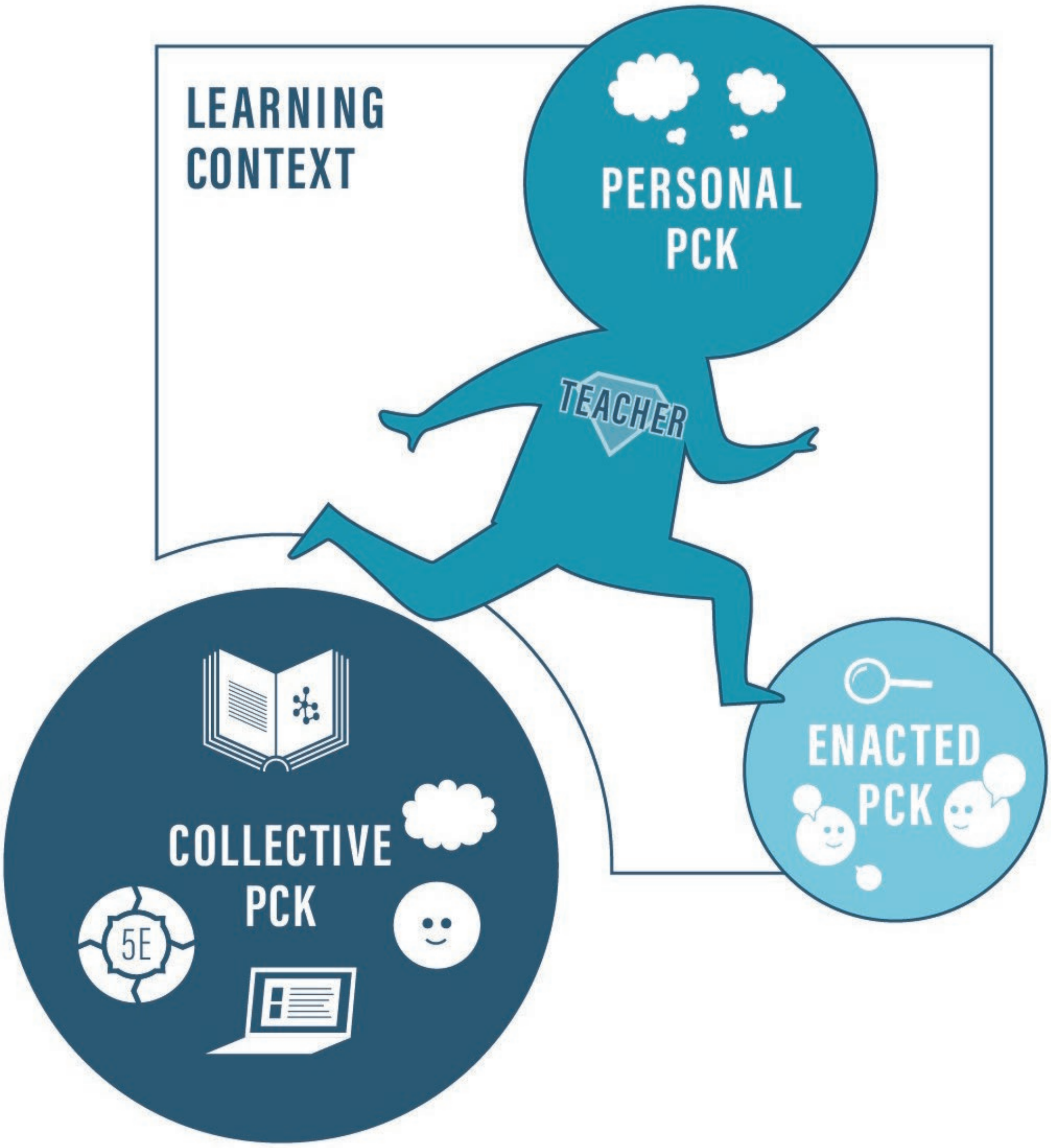

Figure 5: The phenomenon under study: a PST entering a school practicum. cPCK is represented by a model of science teaching, sources of information, and reflections on the PSTs' own classroom experience. pPCK held by the PST is brought into a specific context. ePCK is represented by teaching in a specific lesson with specific students. In summary, the model represents a PST in the process of exchanging PCK into classroom teaching. Illustration: Karin K Johansen design, kakvajo.no

Teachers undergo a critical phase in their professional development as they take the leap from accessing collective PCK (cPCK) and holding personal PCK (pPCK) to enacting it in a classroom (Alonzo et al., 2020). When learning about PCK in teacher education and other places, PSTs remain outside the learning context, and thus their pPCK is not contextualized. Their first contextualization of PCK takes place during school practica, as illustrated in fig. 5. As they enter the science class, they also face the challenge of translating their pPCK into successful classroom teaching. This is illustrated in the figure as pPCK remaining in the PST's head, while visible results are actions in the classroom (i.e., ePCK). Through studying this process, I wanted to understand the nature of the participating PSTs' PCK and make interpretations about its development. To gain insight, I implemented an interpretive research paradigm. I intended to describe the "localized meanings of human experience" (Lederman & Abell, 2014, p. 7), in contrast to a post-positivist paradigm in which PCK levels for large samples are measured and generalized. Localized meanings are not openly accessible, but must be elicited through sustained engagement with the data material and multiple phases of analysis. My own ideas about good teaching, my experiences, and my culture affect this interpretive process. As an example, my views on learning have implications for my research (as outlined in section 2.4).

Fig. 6 illustrates the main approaches of the sub-studies conducted as part of my project. First, a video study was carried out during the PSTs' first school practica. Observation studies have advantages for PCK research as they do not require teachers to articulate (often tacit) PCK, and classroom observations focus on PCK in the context in which it matters most (Alonzo et al., 2012). Therefore, in the initial study (paper 1), I assessed the PSTs' instructional quality using video observations. I applied a research-based video observation manual that captures quality dimensions related to PCK. With the video study, I aimed to uncover what the PSTs were capable of doing in terms of quality science instruction.

Figure 6: Project design.The video study covered all PSTs' science teaching in first year school practica. The SRI studies captured PSTs' reflections from selected lessons in first- and third-year school practica. Illustration: Karin K Johansen design, kakvajo.no

In the second approach, I wanted to capture the PSTs' enacted PCK (ePCK) more directly using SRIs (paper 2 and 3). In a sense, ePCK only exists in the moment of teaching. Researchers have claimed that capturing ePCK would require recording of teachers thinking aloud while teaching (Alonzo et al., 2020). They have also acknowledged this is unrealistic for research, and the best substitute is to record teachers as they reconstruct their thinking from lessons in video SRIs (Alonzo et al., 2020; Park, 2019).

The video study enabled investigation of PSTs' actions and, thus, knowledge embedded in practice. The SRI studies were used to investigate how instruction came about through PSTs' reflections. Such reflections included reflection-in-action, which involved reconstructing thinking from lessons (fig. 1: enacted knowledge and capacity to reason), and reflection-on-action, which involved commenting on and sharing the reasoning behind lessons (fig. 1: knowledge and capacity to reason).

Alongside the two overarching research approaches, I collected secondary data, including lesson plans and field notes from classroom observation. In the lesson plans, the PSTs provided an outline of their lessons and described their CK, contextual factors, student group, instructional strategies, and assessment. The lesson plans were used to keep track of the different lessons, and in paper 3, they were used as a secondary data source to analyze instructional segments. Field notes were used as a secondary data source in paper 3 as well as a starting point for initial and inductive analyses and reflection on my role as a researcher throughout the project.

3.2 Context and participants

3.2.1 Teacher education program

The study was undertaken within a teacher education program educating middle school teachers (grades 5–10, ages 10–16) at UiT The Arctic University of Norway during the years 2017–2020. The program was initiated by a national reform to provide PSTs with deeper knowledge of content and subject didactics and apply more focus to research and development. The goals of this reform were to improve student learning outcomes and increase the status of the teaching profession (Ministry of Education and Research, 2009; Olufsen et al., 2017). The program design was influenced by the Finnish teacher education model (Elstad, 2020). It lasted for five years, focused on research, and included a mandatory master's thesis on subject didactics (UiT The Arctic University of Norway, 2016). The program also included specialized content courses in three school subjects of the students' choice. The three first years of the program are described in table 1. All the PSTs participating in the current study had selected science as their first subject and thus took specialized science courses equivalent to 50 ECTS during years one and three of the program. Science was not the focus of the second year.

In many parts of the world, a common way of organizing science teacher education is to separate science content and methods courses (Etkina, 2010; Fones et al., 1999; Kind, 2019). The program examined in the current project was different, as content knowledge (CK) and PCK were integrated in specialized content courses. The curricula were aligned with the national science curriculum for Norwegian schools, which includes chemistry, physics, geology, biology, health, technology, and the nature of science. In line with the national school curriculum, the specialized science courses focused on practical work, inquiry teaching, and five basic skills: oral skills, reading, writing, digital skills, and numeracy. The courses were focused on science CK, although PCK was also addressed. A PCK focus was evident in textbooks in units on inquiry and argumentation, course instructors' focus on students' understanding of the topics, and modeling of reformed instructional practices. For example, classroom-relevant CK on chemistry was combined with PCK to teach a specific chemistry topic to students.

Table 1: Years 1–3 of the teacher education program for grades 5–10

YEAR	**15 ECTS**	**15 ECTS**	**15 ECTS**	**15 ECTS**		**PRACTICUM**
YEAR 1	Science (joint elementary and middle school PSTs)	Science	Subject 3	P&S (10)	R&D (5)	Field practicum, 3+3 weeks
YEAR 2	Subject 2 (joint elementary and middle school PSTs)	Subject 2	Subject 3	P&S (10)	R&D (5)	Field practicum, 3+3 weeks
YEAR 3	Science (20)	Subject 2 (20)	R&D (5)	R&D thesis		Field practicum, 3+3 weeks

Note. Science = subject 1. P&S: Pedagogy and Students. R&D: Research and Development. 60 ECTS = one year of full-time study. ECTS is shown in brackets when there is a difference from the columns.

The Research and Development (R&D) course covered the nature of science, educational research, and classroom leadership. The Pedagogy and Students course (P&S) included educational law and curricula; how students aged 10–16 learn; and experiences involving planning, enactment, and assessment of instruction (UiT The Arctic University of Norway, 2016).

For two periods each year (one in the fall and one in the spring), PSTs practiced teaching in schools. They were organized into groups of two to three and worked together at a primary or lower secondary school (grade 5–10) for three weeks at a time. They would function as a part of the teacher collegium at the school, following the time schedule of the mentoring schoolteacher. The mentor had a great impact on the practicum experience in terms of which subjects should be taught and the degree of freedom PSTs would get. Except for some days that involved observation, PSTs planned and taught their own lessons on topics assigned by the mentor teacher. A main goal of the first-year school practica was observation and enactment of the teacher role. In the third-year practica, teaching based on national and local curricula was a main focus. In the spring semester during the third year, the PSTs were tasked with writing a thesis based on investigations of their own teaching practices (UiT The Arctic University of Norway, 2016).

3.2.2 First round of data collection

Sixteen PSTs entered the program in 2017. Those who chose science as their subject 1 were invited to participate in the study. A total of 12 PSTs gave their consent to participate. Two groups of three (a total of six) were selected as the case PSTs for the first two sub-studies during the first round of data collection (fig 6). They were aged 19–24 years (table 2). In addition, they were the only ones placed in groups in which all had given consent to participate in the study and had chosen teaching subjects that match the subjects taught by the mentor teachers recruited to the study. The mentor teachers were recruited from those assigned as mentors to the cohort.

Three of the PSTs, Ingvild, Jens, and Sanna (pseudonyms), were placed at school 1 in one grade 7 classroom with 32 students aged 11–12. A female teacher with more than 10 years of experience served as their mentor. She was not certified in science, but she enjoyed teaching the subject. Her mentoring style was supportive. While she did not encourage reform-oriented teaching practice, she did praise PSTs for focusing on students. The other three PSTs, Jakob, Pia, and Lena (pseudonyms), were placed at school 2 in one grade 6 classroom with 20 students aged 10–11. Their male mentor teacher had more than 10 years of experience, and science was a part of his initial teacher education. He was also supportive in his mentoring, and he encouraged project-based teaching across school subjects. This meant that his PSTs taught few science lessons in the first school practicum.

Within both groups, the PSTs and their mentor teacher discussed lesson plans and issues regarding instruction. All PSTs and the mentor teacher were present in all lessons and provided feedback on the lesson to the PST leading it. In the mentoring sessions, both mentor teachers focused on issues regarding general pedagogy, such as the diversity of students, and science topics were a secondary focus. The mentor teachers were responsible for selecting science topics, but the PSTs were allowed to make their own choices regarding how to teach.

3.2.3 Second round of data collection

In year two of the program, the PSTs focused on the subjects they had chosen as their subject 2 (mathematics, social sciences, etc.). In year three of the program (2019–2020), science was again a focus of their coursework and school practica. In this year, I repeated data collection, connecting school practicum experiences to PSTs' learning about how to teach. To make visible the role of specialized science courses, I aimed to contrast science teaching with and without related specialized science course experiences.

In this round of data collection, all participating PSTs were placed at the same lower secondary school, teaching two different classes at grade 8 and 10. Two new mentor teachers were recruited. Both were educated science teachers who had more than 10 years of teaching experience, extensive experience mentoring PSTs, and enthusiasm for science. In addition, both were willing to facilitate opportunities for the PSTs to teach one lesson on a topic for which the PSTs had received instruction in a specialized science course (aligned lesson) and one for which they had not (unaligned lesson).

Of the six PSTs participating in the first round of data collection, four were still in the program: Ingvild, Jens, Jakob, and Pia. They agreed to participate in the second round and were assigned to one of the two mentor teachers. In addition, the school practicum administrator assigned one of the mentor teachers with another PST, Tina. She was invited to the study because I already aimed to follow her school practicum group. Thus, a total of five PSTs were invited to participate in the second round of data collection, as shown in table 2. However, only three PSTs (Jakob, Pia, and Tina) were able to teach at least one unaligned and one aligned lesson. They are the participants on which I report in paper 3.

Pia and Tina taught a grade 8 class. The 25 students in the class did not know each other well, and they were not used to group work in science. Their mentor teacher focused on science content in instruction and provided more feedback on accuracy of representations than other aspects of science teaching. Thus, his mentoring was focused on CK and did not encourage student-centered teaching.

Jakob taught a grade 10 class with 21 students together with Jens and Ingvild. These students showed interest in and knowledge of science, but a lack of focus in some lessons. Their mentor teacher had clear ideas about what should be taught and which strategies would be useful. However, the mentor teacher provided feedback related to both CK and PCK. Jakob showed independence in designing his own lesson scripts, despite explicit guidance from the mentor teacher.

Table 2: The participants, their science background, and their teaching experience.

PST	SCIENCE SPECIALIZATION IN HIGH SCHOOL	TEACHING-RELATED EXPERIENCE	PARTICIPATING IN DATA COLLECTION ROUND
INGVILD	Biology, chemistry, and technology and research	Leader for kids’ activities	1
JENS	None	None	1
SANNA	Advanced mathematics, chemistry, and geology	Leader for kids’ activities	1
JAKOB	Biology	Leader for kids’ activities	1,2
PIA	None	Teaching experience	1,2
LENA	None	Teaching experience	1
TINA	Biology	Leader for kids’ activities	2

To gain insight into PSTs’ knowledge and skills for teaching, I applied multiple research methods during data collection in school practica. The primary methods were video observations and SRIs with PSTs, while lesson plans, field notes, and mentor teacher interviews served as secondary data sources. In the following sections, I discuss the central methods of data collection, how data were analyzed, the quality of the study, and ethical considerations.

3.3 Video observations

Forty-five science lessons taught by the participating PSTs in school practica during the first and third years of the teacher education program were video-recorded. The 21 lessons from year one served as the basis for paper 1. For the sake of time, I chose not to analyze video recordings from year three. I used two small high-resolution video cameras to capture the PSTs' actions. Sound was recorded through a wireless microphone carried by the PST.

The term "video study" refers to research on social or educational reality that is based on analysis of recordings (Janík et al., 2009). Compared to direct observations, video studies reduce the dependency on an observer's skills, such as the ability to quickly write field notes (Hacking, 1983), which are known to influence observation results. Further, an observer will have problems overcoming human limitations and processing enough information to review classroom actions without missing some phenomena or over-emphasizing others (Erickson, 2006). However, video recordings are also selective in what they record. If something happens outside the frame of the camera, it is not recorded and thus is excluded from the study. This is why it is critical for video research to find a balance between recording events close-up and capturing enough of the context (Blikstad-Balas, 2016). As a purpose of the project was to overview pre-service teachers' science teaching, not only specific situations, I chose to capture the whole classroom.

Video studies face challenges alongside their benefits. First, observations are always at risk of capturing situations that are not typical in practice. For example, the PSTs might act differently on camera than otherwise. Additionally, the presence of a researcher and camera equipment in the classroom may affect students' behavior, even though young people are used to video recording devices and the devices were small action cameras on mini tripods. This could be seen as reducing the reliability of video recordings. However, researchers have reported that this actor effect is temporary (Klette, 2009), and I have had similar experiences in the current project. Second, in regard to workload, video material may require a substantial amount of time for handling and analysis (Klette, 2009). I experienced this challenge, as I aimed to gain an overview of instructional quality across PSTs, schools, and instructional segments. Systematic analysis based on clear manuals is one way of overcoming the workload challenge.

3.3.1 Analysis of video data

To analyze recordings in the video study, I used a structured framework for assessment of instructional quality. Observation categories were selected from the Linking Instruction in Science and Student Impact (LISSI) observation manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020). This manual (Appendix) was designed to capture the central dimensions of quality science teaching. I was involved in designing the manual, which we based on the Protocol for Language Arts Teaching Observations (PLATO; Grossman et al., 2013), with additional inspiration from the Electronic Quality of Inquiry Protocol (Marshall et al., 2010) and the video manual used in the Budding Science and Literacy project (Ødegaard et al., 2014).

The LISSI manual was refined through several rounds of review of research and analysis of classroom teaching. This ensured a valid measure of critical dimensions of science teaching practice. Inter-rater reliability was found to be satisfactory (Ødegaard, Kjærnsli, Karlsen, Kersting, et al., 2020).

Twelve of the 19 categories in the LISSI manual were used in our analysis (table 3). These were selected based on my theoretical framework for instructional quality, which includes cognitive activation, discourse features, instructional clarity, and scientific inquiry (see section 2.3). The framework was related to the PCK components focused upon in this thesis: knowledge of students' understanding of science and knowledge of instructional strategies.

In the coding procedure, science lessons were divided into 15-minute segments for analysis (N=71). Each segment was scored from 1–4 on the 12 categories, which represented distinct teaching practices. A score of 1 indicated almost no evidence of the targeted practice, 2 indicated limited evidence, 3 indicated evidence with some weaknesses, and 4 indicated consistent and strong evidence. While the scores for individual categories say little about the general quality of instruction, together, the 12 categories capture important dimensions of quality science instruction. For example, the category *representation of content* is a central part of the instructional clarity dimension of instructional quality, and it is closely related to knowledge of instructional strategies. Table 3 overviews the 12 selected categories and their origins.

Table 3: Categories in the video coding manual, with descriptions of evidence indicating low-end and high-end scores

Evidence for low-end scores (1–2)	Evidence for high-end scores (3–4)
Cognitive activation: Activation of student thinking.	
Connections to Prior Knowledge[1]	
If students' prior knowledge or experiences are referred to, it is done briefly or superficially and is not sufficiently connected to the day's lesson.	Students' prior knowledge or experiences are elicited or referred to multiple times and are connected to the day's lesson.
Intellectual Challenge [1]	
Students spend most of their time on activities or assignments that are rote or recall.	Students spend most of their time on activities or assignments with high academic rigor that promote analysis, interpretation, inferencing, idea generation, or high-level analytical and inferential thinking.
Student Reflection [2]	
If students are encouraged to reflect on their learning, it is only at the level of remembering what the lesson was about.	Students are encouraged to reflect on their understanding of the lesson or to think at higher levels.
Discourse features: Facilitation of science discourse.	
Teacher Role [2]	
The teacher is the center of the lesson or only occasionally facilitates student–student talk.	Rather than being the center of the lesson, the teacher facilitates student–student talk.
Classroom Discourse [1]	
a) Opportunities for student talk: If they arise, opportunities for science-related discussions are short or characterized by recitation. b) Uptake of student responses: Responses by	a) Opportunities for student talk: Open-ended science-related questions are discussed at some length. b) Uptake of student responses: The teacher and students carefully listen to each other and elaborate on or help develop science ideas.

Evidence for low-end scores (1–2)	Evidence for high-end scores (3–4)
the teacher and students responses usually do not elaborate on or help develop students' ideas.	
Instructional clarity: Strategies for teaching new content.	
Representation of Content [1]	
If provided, the teacher's explanations, examples, illustrations, models, and analogies are incomplete, perfunctory, weak, or incorrect.	The teacher presents accurate and clear explanations, examples, illustrations, models, or analogies. Nuances of concepts and student misunderstandings may be addressed.
Use of Academic Language [1]	
The teacher rarely or never uses any scientific language, or it is used but not explained.	The teacher uses and explains scientific language, and students have opportunities to use it.
Feedback [1]	
If the teacher or students provide feedback on students' work or ideas, it is mainly vague, repetitive, perfunctory, or misleading. Suggestions for how to improve performance are procedural rather than substantive.	The teacher or students provide constructive feedback that specifically addresses students' work or ideas.
Practical Activities [4]	
If students interact with objects beyond materials for reading or writing, these practical activities are not tied to learning science concepts.	Students interact with objects beyond materials for reading or writing. Practical activities are connected to learning science concepts.
Scientific Inquiry: Phases of inquiry teaching.	
Preparation for inquiry [3,4]	
No researchable questions, hypotheses, or predictions are developed. However, the teacher may activate students' prior knowledge or invite them to wonder about science.	A researchable question, hypothesis, or prediction is developed. Further inquiry may be planned by the teacher or students.
Data Collection [3,4]	
Students may perform observations or investigations with or without addressing a researchable question, hypothesis, or prediction. Data are not documented.	Students perform investigations to address a researchable question, hypothesis, or prediction. Data are documented and may be systemized.
Consolidation [3,4]	
Students may discuss observations or data. However, while they may draw simple descriptions from them, no conclusions are made.	Students draw conclusions from observations or data. They may connect these to scientific theoretical knowledge and discuss the implications.

Note. The selected categories from the LISSI manual. Literature bases for the categories: [1] Grossman et al. (2013). [2] Marshall et al. (2010). [3] Ødegaard et. al. (2014). [4] A new category in the LISSI manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020).

The second author of paper 1 and I analyzed the video material together. We were both certified as reliable raters of the PLATO categories. To ensure reliable and valid coding, we co-coded 20% of the material. In three cycles, we coded identical segments, discussed and revised any differing scores, and clarified the video observation manual. Of the 14 segments coded in this process, 90.5% were scored identically or within 1 score point by both raters. Then, I coded all 71 segments based on the clarified observation manual.

The long-term nature of the video data was beneficial, as it was available for analysis bit-by-bit, in a well-structured manner, and with both qualitative and quantitative strategies (Roth, 2009). When two coders analyze the material, as we did, the reliability of analyses can increase (Blikstad-Balas, 2016; Janík et al., 2009). Structured analyses are useful for making meaning of complex classroom situations. Validated manuals reduce the impact of personal interpretations on analysis of complex classroom situations due to the use of consistent vocabulary (Klette et al., 2017). They also allow for comparison of results from one study with similar studies (Klette, 2009).

3.4 Stimulated recall interviews

In sub-studies 2 and 3, I used SRIs to prompt PSTs to reconstruct their thinking from when they were teaching. SRIs were conducted shortly after instruction, usually within three hours, to ensure the PSTs still remembered situations in the lesson. Each interview lasted 45–90 minutes. A PST would view a video of their instruction with me, and I would explain that I was interested in what she thought during instruction. The PSTs were given control over the video, and they could pause the recording when they recalled thoughts from the lesson to share them verbally. One short reflection-in-action shared by Ingvild in her first SRI was as follows: “I just picked a fun example that struck my mind as I stood there. I thought ‘you can say that’, just to regret the choice as I was in the middle of the example.” After reconstructing reflection-in-action, the PSTs typically commented on the situation in retrospect (reflection-on-action). Sometimes, I prompted further reflection to gain a deeper understanding of the PST’s thinking, and I would ask about which sources of knowledge were relevant to the thoughts shared by the PST.

SRIs were used to answer the second research question, which concerns how PSTs develop their pPCK and how this knowledge is transformed into ePCK during science teaching.

The SRI approach was broader than the video approach in one sense, but more fine-grained in another sense. The PSTs shared reflections from not only the teaching phase but also the planning phase. Additionally, through retrospective comments on the situations, the reflection phase was covered. Thus, the approach was broad. However, it was also fine-grained because multiple micro cycles of ePCK were evident in the PSTs' reflections. For each micro cycle, they shared their thinking during a situation with students in the classroom, how they considered responding in that situation, and evaluation of how it turned out in the end.

The SRIs captured PSTs' knowledge, enacted knowledge, and capacity to reason (see sections 2 and 3.1). Pedagogical reasoning during classroom teaching is often chaotic in nature. Teachers use their mental models, or reflection-in-action, to handle uncertain situations in the classroom (Henderson & Tallman, 2006; Schön, 1992). Mental models are cognitive representations reflecting the structure of real-life-situations (Henderson & Tallman, 2006). In classroom teaching, ePCK represents mental models. I used videos of the PSTs' recent teaching to prompt sharing of these models. This use of SRIs enables research on elements from the chaotic and non-linear processes of classroom teaching with less of the filtering effect teachers typically add when asked to reflect on a lesson in retrospect (reflection-on-action) (Henderson & Tallman, 2006; Meade & McMeniman, 1992).

Due to its focus on individual PSTs' reflections, the SRI approach emphasizes cognitive aspects of teacher learning. I did not focus on how the PSTs in practice groups understood and developed PCK and teaching skills. This aligns with the PCK approach developed by Park and Chen (2012), which leaves teachers' interaction with contextual factors in the background (Park, 2019).

My use of SRIs prompted reflection-in-action. This is not obvious, as the reflections recorded on tape during SRIs were formulated in an interview situation, which differs from the classroom situation in space and time. Thus, one could say that reflection-on-action is what is possible to record in such interviews. However, I argue that the method brought about different reflections than would a traditional interview in which participants reflect on their practice. When I invited PSTs to participate the study and introduced the interview, I made clear that I wanted the PSTs to share their thoughts from the viewed lesson without filter. Further, I made clear that I did not know what was right and wrong to think or do in their lessons. The quotes from SRIs presented in papers 2 and 3 illustrate that the PSTs did share reflection-in-action. Earlier research has also shown that it is possible to recall reflections from a recent teaching event through the use of SRIs (Ericsson & Simon, 1993; Gess-Newsome, 2015; Henderson & Tallman, 2006; Meade & McMeniman, 1992).

Another point of concern regarding the use of SRIs was that I wanted to leave the interview setting open for PSTs to freely share their thoughts from the lesson, but I was interested in specific elements of instruction and knowledge of instructional strategies. Thus, the interviewee might have filtered reflections assumed not to be of interest to me. I chose to be open with the PSTs about my focus, so they knew what to expect before the interview.

A third issue is how I draw knowledge about the PSTs' PCK and development thereof from their statements about specific teaching situations. It is important to keep in mind that I access only subsets of their PCK related to specific situations. I argue that these subsets, which are manifested as ePCK, can represent their pPCK. However, of course, they cannot present a holistic picture of their pPCK.

3.4.1 Analysis of stimulated recall interview data

The purposes of my analysis of SRI data were to capture elements of the knowledge structures enacted by PSTs in their classroom teaching and to relate their knowledge and practices to sources of PCK. The second author of papers 2 and 3 and I considered a variety of approaches to interpret the PSTs' reflections in a meaningful and valid way. We adopted an inductive approach to identify each PST's PCK integrations. We found the final analysis route, presented below, to be most true to the actual data and still produce useful interpretations:

1. In both SRI studies (papers 2 and 3), SRIs were first transcribed with the help of automated dictation in a text processing program, and then imported into NVivo software (QSR International, 2019).
2. The transcripts were then divided into instructional segments. An instructional segment was defined a section of the interview related to a particular instructional strategy (e.g., a role-play about fundamental states) or another distinct phase of instruction, such as a specific example of a strategy (e.g., moving from overviewing a model of the human digestive system to teaching about a detail of the model, like the appendix) or shifting focus to a different student.
3. Next, the material was coded based on the PCK sub-categories in the Magnusson model as well as inductive codes covering emerging PK in the SRIs. Instructional segments where PSTs simultaneously drew upon knowledge of students and knowledge of instructional strategies were analyzed as integrated segments.
4. Further analysis of integrated segments was partly deductive, as it was structured around sub-components of two central PCK components: knowledge of students' understanding of science and knowledge of instructional strategies. It was also partly inductive. First, components of PK emerged as central in the PSTs' reflections about teaching specific science topics and were included in the analysis. Second, sub-categories of PCK were added to those included in the Magnusson model. Third, the integrated segments were coded for rationale, which was the reason PSTs used an instructional strategy. In sub-study 3, analyses from this step resulted in findings that were valid for all three participating PSTs.
5. In sub-study 2, the quantity of each sub-code and the frequency of integrations among them were illustrated in PCK maps, inspired by Park and Chen (2012). Maps for each PST showed integration of one or more categories of knowledge of students, one category of instructional strategies, and one rationale for using the strategy. In the maps, font sizes and thickness of arrows reflected quantification of categories and connections between them across the total of

integrated segments for a PST. Figure 7 shows an example map. The font size illustrates the frequency of that sub-code in all of the PST's integrated segments. Arrows illustrate the quantity of integrations. The example map shows that, for the case of Sanna, 20% or more of the total of 21 integrated segments were coded to *prior knowledge* (sub-category of knowledge of students' understanding of science), and *topic-specific representations* (sub-category of knowledge of instructional strategies). The integration of *prior knowledge* and *topic-specific representations* is represented with a thin, continuous arrow. The map indicates that 10–14% of the 21 integrated segments were double-coded to these subcodes. Further, Sanna's map shows that she frequently enacted *topic-specific discussions* with *student participation* as the rationale, informed by knowledge of *general student characteristics*. It also shows that she never addressed specific *misconceptions.* The PCK maps for each PST were used in analysis, resulting in findings that were valid for all six PSTs.

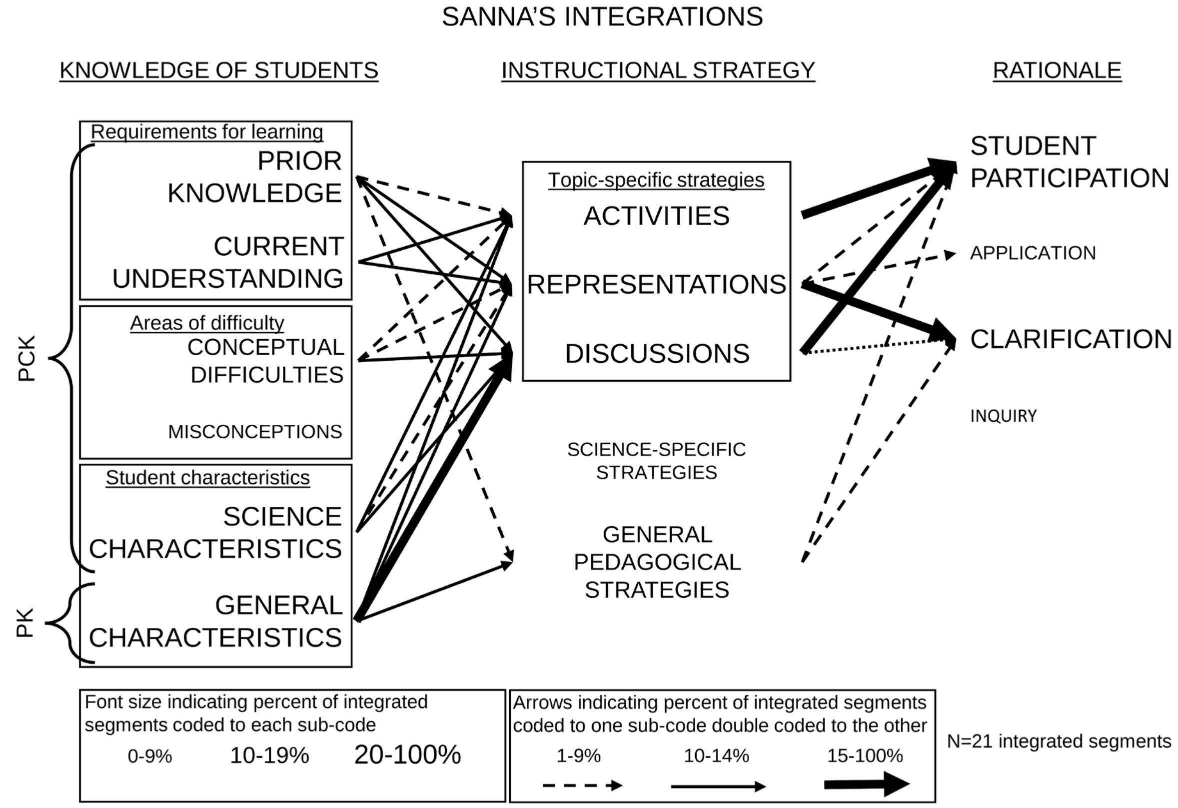

Figure 7: PCK map of Sanna's integrations of knowledge of students and knowledge of instructional strategies

6. In both sub-studies 2 and 3, I identified sources of PCK and integrations of knowledge of students' understanding of science and knowledge of instructional strategies. Codes emerged from the data, indicating from where the PSTs gained the knowledge that informed their instructional decisions. In this step, I used causation coding (Miles et al., 2014) to determine what caused PSTs to enact certain strategies.
7. In sub-study 3, to capture the impact of specialized science courses on teaching practice, I performed variable-oriented analysis of PSTs' responses to specific questions and other relevant utterances (Miles et al., 2014). I aimed to capture themes regarding the impact of specialized science courses on classroom teaching across the case PSTs.

My fine-grained analysis of individual instructional segments and detailed representation of PCK integrations represents an innovation in PCK research methodology. In this way, I respond to Park (2019), who encouraged the development of innovative analytic methods for exploring pedagogical reasoning and ePCK. I found the PCK map approach useful (Park & Chen, 2012; Park & Suh, 2019), but in order to capture the mechanisms of ePCK at a proper level of detail, I had to tweak and adjust available methods.

3.5 Validity and reliability issues

Validity and reliability issues were important throughout the research process. First, to answer the first overarching research question, a central challenge was to capture a valid understanding of how the PSTs taught their science lessons. My use of categories from the LISSI standardized video observation manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020) strengthened validity of video analyses. Two researchers co-coded parts of the material and discussed different interpretations of classroom practice. This kind of triangulation reduced the likelihood of misinterpretations in video analysis (Stake, 2005). Section 3.3 provides further details on how validity and reliability were improved in the video study.

To answer the second research question, which concerned PSTs' use of PCK during teaching situations, I had to gain a valid understanding of their thinking processes. I could have inferred their thinking from video analysis or interviewed the PSTs and asked for reflections on how they drew upon PCK. However, such strategies would leave considerable potential for misinterpretation based on my ideas and goals (Henderson & Tallman, 2006). In section 3.4, I explained why SRIs are valid and reliable as a data source for PSTs' knowledge, knowledge in action, and capacity to reason. To ensure that interviewees still remember the situations and thus can recall their reflection-in-action, SRIs should be carried out shortly after the situation. Reports indicate that SRIs carried out within two days have 95% accuracy (Henderson & Tallman, 2006). Typically, I conducted the SRIs within two hours after the lesson. The validity of the analysis was increased by thorough examination of SRI transcripts and then innovation based on the PCK approach (Park & Chen, 2012). This provided a valid, fine-grained picture of the PSTs' PCK integrations. For paper 3, I did a member check with the participants. They comment on my interpretations in the analysis of SRI data, resulting in increased credibility of the presented results.

3.6 Ethical considerations

Ethical considerations were central in all phases of the project, from recruitment of participants to publication. When PSTs were invited to participate in the project, I emphasized their freedom of participation and ensured that informed consent was given for participation. The Norwegian Centre for Research Data (NSD) was notified prior to data collection. Based on my descriptions of the project design and documentation of letters of invitation and interview guides, NSD approved the project (see appendix).

PSTs and mentor teachers were invited to participate in the study. Mentor teachers contacted students and parents on my behalf with information and an invitation to participate in the study. In an effort to approach potential participants with respect, I strived to highlight that participation was voluntary, and withdrawing from the study at any time would not negatively impact their situation as PSTs, mentor teachers with a relationship to the university, or students with a relationship to the school. Consent for participation was not received for a few students in the observed classrooms. These students were not recorded.

3.6.1 Video recordings in classrooms

Video recordings in classrooms over time raise ethical issues. Children's right to human dignity and integrity is highlighted in Norwegian ethical guidelines for social sciences and the humanities (NESH, 2016). When invited to participate in a research project, children have limited abilities and power compared to adults (Hill, 2005). Concern about the use of images of children in research also has increased (Hammersley & Traianou, 2012). Despite this, my supervisors and I agreed that video recordings were necessary to fulfil the purpose of the project.

Classroom research without recordings would also raise ethical issues, some of which are related to the dependence on a single researcher in the classroom. First, a single observer has limited capacity for simultaneous observations, limiting the information that can be analyzed (Erickson, 2006). Further, my judgement of instructional quality would have been less transparent, and building reliable analyses with the use of multiple raters would not have been possible. This would have hindered me from keeping the research process open and ensuring systematicity and documentation, which are principles of ethically sound research according to the Norwegian National Committees for Research Ethics (ETIKKOM, 2014).

The presence of recording equipment and a researcher affect social settings in classrooms (Blikstad-Balas, 2016). However, in general, the students in the current project seemed to forget the video cameras and became used to the presence of a researcher. This has also been found in prior classroom studies (Blikstad-Balas, 2016). I asked the PSTs to guide me to act properly as a guest given the actual context. In two lessons on sexual health, the recordings were limited to audio only, as advised by the PST. Although I acknowledge that I did intervene into the classroom ecology, this is a necessity in qualitative research.

The nature of PSTs' teaching may also have been interrupted by the video recordings. In the interviews, PSTs assured me that, after a short while, they were not affected by the video recordings. However, PSTs generally tend to deliver excellent instruction when observed by university staff. This may be grounded in a false belief that every observation by university staff is a summative assessment. I do not know the PSTs' motivations, but my clear impression from following the participant PSTs through school practica is that they were oriented toward students' learning, rather than me or the university.

For the analysis phase of my project, it was necessary to determine what quality instruction entails. Assessment of instructional quality was central in my analysis. As the number of participants was low (N=7), descriptions of the material allow peer PSTs to identify individuals in my publications. Therefore, varieties in the material were discussed without being specific about individual PSTs.

3.6.2 Sensitive data

The classroom video data were sensitive, as students and other persons in the classrooms could be easily identified. Depending on the placement of the camera and audio recording device, private conversations and information such as computer passwords may be recorded in video studies (Frøyland et al., 2015). In our project, cameras were placed at a distance from individual students, and PSTs were instructed to mute their microphone whenever necessary. When I observed PSTs entering situations where conversations irrelevant to instruction took place, I muted the audio recording. I ensured that data were safely stored in accordance with guidelines from the National Committee for Research Ethics in the Social Sciences and the Humanities (NESH, 2016). All data were locked, and I was the only person with access. All digital data were also encrypted.

3.6.3 My role as researcher

When I started this project, I was a newly educated teacher with experience from a similar teacher education program to the one in the current project. As part of my PhD work duties, I served as a specialized science course instructor. I taught the participating PSTs in two units (the solar system, waves and sound) for a total of 12 hours. Although I was a researcher, I also identified as a teacher, and I understood the context and participants better than an external researcher. This helped me to select a relevant approach to fulfill the purpose of the project, maintain open communication with the participants, and interpret the results.

However, I acknowledge that my proximity to the participants represents a potential ethical issue. Researchers have a special responsibility to take care of the interests of vulnerable groups (NESH, 2016). In some sense, I should view PSTs as a vulnerable group, as they are institutionalized and must submit to the university system. Instructors should be aware that their students are potentially subject to force or manipulation when they are invited to participate in research projects (Moreno, 1998). On the other hand, the PSTs in the current project were mature individuals who were seemingly capable of making their own decisions. Persons in groups like that should not mainly be seen as vulnerable, but treated with equality (Moreno, 1998). To address the issue, I invited the PSTs to participate in the study before I met them as an instructor.

I did not want PSTs to view me as an evaluator of their knowledge and practices. Therefore, I did not participate in formal assessment of the PSTs. Following PSTs entering a teacher education program provided a great opportunity to maintain contact over time. In the end, this was beneficial for them as well, as it provided additional opportunities for them to reflect on their practice and knowledge.

4 Findings

The overarching research questions in this thesis were (1) “How do pre-service science teachers (PSTs) enact their first pieces of professional knowledge, especially pedagogical content knowledge (PCK), in school practica?” and (2) “How do PSTs develop personal PCK (pPCK), and how is this knowledge transformed into enacted PCK (ePCK) during science teaching?” Each of the three papers contribute to answering these questions. In this chapter, I summarize the findings. For paper 1, I describe the PSTs’ science teaching in first-year school practica. For the other two papers, I describe how they drew upon integrated PCK in the same lessons (paper 2) and which sources of knowledge for teaching inspired these integrations (papers 2 and 3). Table 4 overviews the research questions, data, analysis, and results. After summarizing the results of each paper, I provide a synthesis of them, using the refined consensus model as a framework to view PCK and classroom teaching together.

Table 4: Overview of papers and their research questions, data, analyses, and results

	RESEARCH QUESTION	**DATA/ANALYSIS**	**RESULTS**
1	What is the quality of six beginner pre-service middle school teachers' science instruction in school practica?	Video observation data (N=21 lessons) Video observation manual eliciting quality science instruction (LISSI manual)	- PSTs activated students' prior knowledge, but intellectually challenged students to only a moderate degree - Discourse in the classrooms was dialogic, and PSTs facilitated student–student talk - PSTs sometimes struggled to present science content with clarity, but they effectively used practical activities - Inquiry teaching was seldom or poorly implemented - The PSTs' teaching was characterized by several aspects of student-centered teaching
2	1) What is the frequency and nature of PSTs' integration of the PCK components knowledge of students' understanding of science and knowledge of instructional strategies? 2) What are the sources that contribute to their PCK integration?	SRI data, lesson plans[1] (N=12 lessons) Inductive and deductive analyses represented by detailed PCK maps Analysis of sources	- The PSTs had highly integrated knowledge of students with knowledge of instructional strategies - In the integrated segments, the PSTs varied in their emphasis within the category of knowledge of students' understanding of science. Some of the PSTs focused on requirements for learning and areas of difficulty, while others focused on student characteristics - In the integrated segments, the major of the instructional strategies were topic-specific; these strategies were used to either clarify the science content, apply it to a familiar setting, or engage students - The PSTs referred specialized science courses, peer PSTs, personal learning experiences, and mentor teachers as the sources of their knowledge of students' understanding of science, knowledge of instructional strategies, and integration of those

	RESEARCH QUESTION	DATA/ANALYSIS	RESULTS
3	1) In three Norwegian science PSTs' practica in lower secondary school, what were the differences, if any, between lessons aligned^2 and unaligned with specialized science courses? 2) What were these PSTs' perceptions of how they drew upon specialized science courses?	SRI data, lesson plans^1, video observation data^1 (N=6 lessons) Inductive and deductive qualitative analysis Analysis of sources	- Science- and topic-specific strategies were more often enacted in the aligned lessons - In the aligned lessons, the participating PSTs more often based their instructional decisions on topic- and science-specific PCK rationales - Instructional strategies in the aligned lessons were more often informed by knowledge of students' understanding of the topic - PST highlighted specialized science courses as an important influence on their knowledge, skills, and self-efficacy for teaching science

Note. [1]Secondary data [2]Aligned lessons were on topics previously taught to PSTs in specialized science courses for teachers.

4.1 Paper 1: Instructional quality

Sæleset, J., Olufsen, M., & Karlsen, S. (Under review). Quality of beginner pre-service teachers’ science instruction. *Acta Didactica Norden.*

In paper 1, I investigated the following research question: “What is the quality of six beginner pre-service middle school teachers’ science instruction in school practica?” This paper focused on the observable aspects of pre-service teachers’ classroom practices, using instructional quality as a framework. I focused on the following quality dimensions: cognitive activation, discourse features, instructional clarity, and scientific inquiry.

Twenty-one science lessons were videotaped in six PSTs’ practica in grade 6 and 7, which took place during their first year in the teacher education program. These lessons were analyzed using 12 video coding categories from the LISSI video coding manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020). The categories were related to PCK, particularly knowledge of students’ understanding of science and knowledge of instructional strategies. For example, the first category, *connections to prior knowledge*, was related to what PSTs knew about students’ prior knowledge and experiences and how they facilitated connections to the day’s lesson with the selected instructional strategies. Each 15-minute segment was scored from 1–4 on each category based on evidence in the video. The PSTs had different scores, but there were many similarities. Further, contextual factors were considered, but only some categories showed differences between the first and second school practica, lessons, location of segment within lessons, and whether or not the lesson went into depth on conceptually difficult elements. The results include descriptions of PSTs’ teaching along the four dimensions of instructional quality. The scores on several of these dimensions reveal student-centered teaching.

Here I list the main results of the study. First, PSTs activated students’ prior knowledge, but intellectually challenged students to only a moderate degree. In almost every lesson, PSTs referred to students’ experiences and knowledge and connected it to the topic at hand. However, the categories *intellectual challenge* and *student* *reflection* indicated that PSTs struggled to make the instruction intellectually challenging and to prompt students to reflect upon their learning. Instructional segments were largely characterized by assignments, activities, and questions that focused on rote learning or recall of facts. When students were challenged to analyze, interpret, infer, generate ideas, or otherwise think analytically and inferentially, this was often accomplished through quality classroom discourse.

Second, discourse in the classrooms was dialogic, and PSTs facilitated student–student talk. Communication patterns in the classrooms demonstrated that PSTs facilitated student participation in scientific discussions rather than just listening and responding to direct questions. In many segments, students' contributions to the discourse were acknowledged as important, and PSTs advanced the conversations rather than closing them.

Third, PSTs struggled to present complex science content with clarity, but effectively used practical activities. Differences among science topics were evident. In many lessons, especially when PSTs went into depth on abstract and dynamic topics, they rarely provided accurate and clear illustrations, examples, models, analogies, or explanations of the science content. PSTs were able to provide more accurate and clear representations during planned presentations. When they had to engage in unplanned interactions, their instruction sometimes indicated their limited content knowledge (CK) and scored lower on *representation of content*. Also, instructional clarity emerged as an issue during analysis of their feedback practices. Students were usually provided with no, vague, or unspecific feedback on their work or ideas. Practical activities, which included interaction with objects beyond materials for reading or writing, were used in a more proper way. In almost half the segments, practical activities were used. In most cases, the activities were tied to science concept learning.

Fourth, inquiry teaching was seldom or poorly implemented. Inquiry teaching was analyzed as three distinct phases: *preparation for inquiry*, *data collection*, and *consolidation*. The potential for inquiry work identified in the preparation phase was not exploited, as few lessons included the important element of formulating of a researchable question, hypothesis, or prediction. As a result, few data were collected, and limited consolidation of knowledge from inquiry was observed.

Finally, characteristics of PSTs' teaching across the material were related to student-centered science teaching practices. Indeed, the participating PSTs (a) organized their classes with frequent group work as well as whole-class discussions, (b) facilitated student–student talk, (c) elicited and connected to students' prior knowledge or experiences, and (d) facilitated high-quality discourse in which students' contributions were valued. PSTs rarely focused on transferring knowledge to students or acted as the center of the classroom. Instead, they focused on facilitating opportunities for students to construct their own understanding.

4.2 Paper 2: Pedagogical content knowledge integration

Sæleset, J., & Friedrichsen, P. (2021). Pre-service science teachers' pedagogical content knowledge integration of students' understanding in science and instructional strategies. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(5). https://doi.org/10.29333/ejmste/10859

Based on some of the same video recordings analyzed in paper 1, I carried out stimulated recall interviews (SRIs) with the PSTs teaching the lessons. These interviews were conducted shortly after the lessons and were intended to capture reflection-in-action from the classroom. The reflections elicited in SRIs were analyzed in detail, resulting in PCK maps that show the integration of knowledge of students' understanding of science and knowledge of instructional strategies. In paper 2, I sought to answer two research questions: (1) "What is the frequency and nature of PSTs' integration of the PCK components knowledge of students' understanding of science and knowledge of instructional strategies?" and (2) "What are the sources that contribute to their PCK integration?"

The first three findings respond to the first research question. The first and second findings showed that PSTs included multiple kinds of knowledge about students into their instructional decisions. The PSTs held knowledge about students' understanding of science both at the general level and the level of the specific students they taught. In most instructional segments, they integrated this knowledge with knowledge of instructional strategies. Knowledge of students often directly informed their choice of instructional strategies. This means that the PSTs were oriented toward supporting students in their learning rather than following curricula or giving instruction without taking students' ideas into account.

The PCK maps show differences among the PSTs in terms of which kind of knowledge about students was emphasized. Half of the PSTs were focused on students' knowledge and understanding of science content as well as their difficulties and misconceptions. The other three PSTs focused on students' individual characteristics (i.e., how students approach specific science topics) and general characteristics (e.g., students' context).

The third finding identified which kinds of instructional strategies were used and why PSTs used them. In the integrated segments, the main instructional strategies were topic-specific (i.e., developed and/or adapted for the specific science topic) representations, activities, and discussions. In just a few of the studied instructional segments, PSTs used science-specific strategies, which were suitable across science topics, and general pedagogical strategies, which were suitable across school subjects.

Based on how the PSTs commented their teaching, I inferred the rationales for why PSTs used certain instructional strategies. Topic-specific strategies were often enacted to clarify the science content, apply it to a setting familiar to the students, or engage students.

In response to the second research question in paper 2, I identified sources contributing to PSTs' PCK integration. The PSTs referred to specialized science courses, peer PSTs, personal learning experiences, and mentor teachers as sources of knowledge of students' understanding of science, knowledge of instructional strategies, and integrations thereof. Notably, specialized science courses were the most frequently mentioned source, as PSTs had recently entered the program at the time of data collection. Peer PSTs worked together in groups of three during school practica and discussed teaching with their mentor teachers. This gave them many opportunities to draw on each other's knowledge.

4.3 Paper 3: Classroom impact from specialized science courses

Sæleset, J., & Friedrichsen, P. (Under review). A case study of specialized science courses in teacher education and their impact on classroom teaching. *Journal of Science Teacher Education.*

The third paper was based on data collection in year three of the teacher education program. In this study, I videotaped four of the PSTs studied in sub-studies 1 and 2 as well as one additional PST as they taught science in lower secondary school practica. Two of the PSTs from sub-studies 1 and 2 were not available to participate in the study.

Again, I conducted SRIs and asked follow up-questions. I wanted to follow up on the finding from paper 2 that specialized science courses were a major source of integrated PCK. Therefore, I aimed to understand whether and how experiences from specialized science courses were manifested in the enactment of PCK. Three of the PSTs taught one lesson on a topic that was covered in a specialized science course (aligned lessons) and one lesson on a topic that was not taught in a specialized science course (unaligned lessons). In the aligned lessons, the PSTs taught about oil and oil-based products, stars, the sun, northern lights, moon phases, and seasons. In the unaligned lessons, the PSTs taught about alcohols, animal cells, and oxygenation in lungs.

The results indicated three findings regarding research question 1: In three Norwegian science PSTs' practica in lower secondary school, what were the differences, if any, between lessons aligned and unaligned with specialized science courses? First, I found that specialized science courses directed PSTs to use instructional strategies specifically designed for teaching science. Indeed, science- and topic-specific strategies were more often enacted in aligned lessons. From the SRIs, observations, and lesson plans, I found that the PSTs drew upon knowledge from the specialized science courses in their instruction on the aligned topics. In all instructional segments, the PSTs mostly used topic- or science-specific strategies. In the unaligned lessons, however, they relied more on general pedagogical strategies.

The second finding indicated that the PSTs used different rationales for their instructional strategies in aligned lessons. In aligned lessons, PSTs used more PCK rationales. In other words, the reasons for instructional decisions were more grounded in topic- and science-specific PCK rather than pedagogical knowledge (PK). For example, in one unaligned lesson, the decision to use an online video about animal cells was grounded in a PK rationale about the need for variation in instruction. In contrast, in an aligned lesson, the decision to use an online video about distances in space was grounded in a PCK rationale about the need to address a specific misconception about the topic.

The third finding on the differences between aligned and unaligned lessons indicated increased integration of knowledge of students' understanding of science and knowledge of instructional strategies in aligned lessons. This integration is critical for PCK development (Chan & Hume, 2019; van Driel et al., 2014). I found that specialized science courses amplify its occurrence in PSTs' classroom teaching. Integrated PCK was enacted when, for example, PSTs used knowledge about common misconceptions learned in specialized science courses and showed that they were prepared to address these misconceptions with instructional strategies.

The second research question in paper 3 was "What were these PSTs' perceptions of how they drew upon specialized science courses?" The PSTs reported that specialized science courses had a major impact on their CK, PCK, and self-efficacy for science teaching. In their experience, the most useful specialized science course lessons were those in which CK was presented at the level of their future students and with an emphasis on PCK and student participation. Specialized science course lessons that focused on CK beyond what their future students were supposed to learn were viewed as less useful for their teaching in grades 5–10. The PSTs also reported that inquiry teaching and laboratory experiments in specialized science courses developed their self-efficacy for science teaching.

4.4 How the findings relate to the refined consensus model of pedagogical content knowledge

In this section, I discuss how my research empirically contributes to the realms of PCK and the knowledge exchanges represented in the refined consensus model (see section 2.1.2). By using the shared vocabulary provided in the refined consensus model, my thesis helps to connect theory and practice in science teaching. The current chapter prepares for the discussion by explaining how the refined consensus model can be used to visualize connections among cPCK, pPCK, and ePCK. It also specifies two aspects that may threaten successful exchange from knowledge about teaching to classroom practice: contextual factors and filters within knowledge exchanges.

The innermost circle of the refined consensus model represents the realm of ePCK. ePCK describes PCK in use during the three phases of teaching science lessons: plan, teach, and reflect (Carlson et al., 2020). Both overarching research questions of this thesis aim to unpack pre-service science teachers' ePCK in school practica, how they teach, and how they draw upon PCK during instruction. I addressed these ideas through video analysis of the teach phase (paper 1) and analysis of PSTs' reflections on the plan, teach, and reflect phases (paper 2 and 3).

PCK enacted in one lesson is a subset of the teachers' pPCK. Based on my study of PCK in action in lesson after lesson, I described subsets of the PSTs' pPCK for teaching the observed topics. In the refined consensus model, pPCK is located in the concentric circle outside ePCK, and it refers to all knowledge held by a teacher about teaching one specific science topic. The video analysis (paper 1) enabled a surface description of elements of the PSTs' pPCK embedded in teaching practice, while reflections from the lesson in SRIs (paper 2 and 3) enabled deeper understanding of their pPCK. Finally, PSTs responded to follow-up questions in SRIs where I specifically prompted them to share pPCK by, for example, explaining alternatives they considered when designing the lesson. This reveals pPCK that the teacher did not utilize during teaching (Chan & Hume, 2019).

pPCK is located within a learning context that includes the broader educational climate, a specific classroom learning environment, and individual student attributes.

Thus, the four classrooms studied in this project represent four unique learning contexts. However, the educational climate, PSTs' teacher education program, school grade level, and structure of school practica were similar for different participants. Differences included mentor teachers' education and mentoring style, how PSTs were treated at the practicum schools, and student characteristics. In addition, each of the 45 lessons represent a unique learning context. This level of context is not illustrated in the refined consensus model but may be covered by the double-ended arrows representing knowledge exchange between pPCK and ePCK.

The outermost circle in the refined consensus model represents cPCK. This is available PCK for teaching a specific topic across a community. Communities with shared cPCK may consist of colleagues at a school or the larger community of PCK researchers. In my research, this realm is represented by sources of the participants' pPCK (papers 2 and 3). PSTs spontaneously shared reflections on these sources in the SRIs. If they did not, I prompted them to. In this way, I studied the cPCK bases from which the PSTs built their pPCK and the way in which this translated to classroom teaching.

In this section, I have shown how the current thesis relates to PCK realms in the refined consensus model. During the project, I also investigated connections between realms. Translations among the realms of cPCK, pPCK, and ePCK are mediated by knowledge exchanges, which are represented by double-headed arrows in the refined consensus model. These knowledge exchanges are central in PCK development. This is because solid cPCK is not useful for the teacher if it is not exchanged into pPCK. Further, it is of no benefit for students unless it is successfully enacted. Classroom teaching should contribute to developing a teachers' PCK, and each teacher should contribute to shared cPCK.

In the current project, I focus on two specific knowledge exchanges. First, through studying classroom teaching and using SRIs, I focus on the PSTs' exchange from pPCK to ePCK. Second, I focused on how cPCK from specialized science courses and other sources contributed to participants' development of pPCK.

5 Discussion

In this chapter, I discuss the key findings presented in chapter 4. In 1986, Lee Shulman shared a vision of "professionals who are capable not only of acting, but of enacting – of acting in a manner that is self-conscious with respect to what their act is a case of, or to what their act entail" (Shulman, 1986, p. 8). His vision for the education of teachers who not just act, but enact a professional knowledge base, inspired many educational researchers. The exploration of how teaching practice is grounded in professional knowledge is ongoing.

In the current project, I have investigated PSTs' development of knowledge for teaching science and how this informs the enactment of teaching. I have implemented two theoretical frameworks that characterize good teachers: PCK and instructional quality.

The results confirm and extend current insights into the connections between PCK and quality instruction. From previous research, we know that the ability to perform quality teaching can be derived from teachers' knowledge base, especially PCK (Fauth et al., 2019; Kulgemeyer et al., 2020; Park et al., 2011). Alonzo et al. (2012) showed how knowledge of students' understanding of science and knowledge of instructional strategies specifically led to student-centered teaching.

The focus of the current project was PSTs' competence to combine knowledge of students' understanding of science and knowledge of instructional strategies. The case study of seven PSTs explored how this competence results in quality science teaching. From the SRI studies, I identified the PSTs' nuanced knowledge of students, which informed their instructional decisions. From video observations, I found that these decisions result in science teaching with certain qualities as well as limitations to their practice. The following discussion is organized according to three main points: (1) the PSTs' student-centered teaching (section 5.1), (2) how PSTs navigated the challenges of communicating science CK to students (section 5.2), and (3) characteristics of PCK development (section 5.3).

5.1 Teaching with students in mind

The participating PSTs taught science with a sustained focus on students and students' learning. Combination of data from the same first-year lessons, which were presented in papers 1 and 2, allows for data triangulation (Yin, 2009). Data from video and stimulated recall interviews (SRIs) revealed that PSTs were able to focus on their students and give student-centered teaching. Video analyses showed how the teaching played out across lessons and classrooms, and SRIs provided insight into the PCK behind some of those lessons. Data from year three, which was presented in paper 3, deepened the findings. PSTs did not just consider students to be passive recipients of knowledge. Rather, the PSTs' reflections revolved around their students' prior knowledge, their needs and interests, and their learning. In addition, the PSTs' selection of instructional strategies was often grounded in these reflections. In this section, I elaborate on how student-centered teaching came about.

Although the PSTs reflected on their role as teachers, their main concern was students. First, a focus on students was identified in the PSTs' use of PCK. They held and enacted knowledge of students' understanding of science and integrated this with knowledge of instructional strategies. This finding represents a contrast to prior research, which indicates that beginning teachers lack PCK for teaching specific topics (Friedrichsen, 2015; Kind, 2009b; Schneider & Plasman, 2011; van Driel et al., 1998), and, thereby, exhibit poor integration of PCK components (Akin & Uzuntiryaki-Kondakci, 2018; Kind, 2009b; Sickel & Friedrichsen, 2018). The participating PSTs in sub-studies 1 and 2 used knowledge of students, including requirements for learning, areas of difficulty, and student characteristics, in a nuanced manner. This means that, for example, PSTs did not limit their attention to what students had learnt in prior science lessons, or to what they thought was their job as teachers (i.e., to continue teaching students where the prior teacher left off). Rather, the PSTs designed lessons and made in-class decisions in response to what they knew about their specific students and students in general. For student learning to occur, it is necessary to connect content knowledge (CK) and pedagogical knowledge (PK) (Kind & Chan, 2019). One such connection is the PSTs' use of knowledge about students, which was outlined above. In a study of PSTs in an alternative certification program for teachers, Brown (2008) found that the case PSTs held PCK with integrated knowledge of students' understanding of science and knowledge of instructional strategies. However, they struggled to reflect knowledge of students in their instruction, which remained teacher-centered. This contrasts the current project, where integrations evidently resulted in student-centered teaching.

Second, by investigating the PSTs' rationales for enacting instructional strategies, I deepened my understanding of how they integrated knowledge of students into instructional decisions. Fine-grained analyses of SRI data showed that they used a variety of rationales in year one (paper 2) and even more nuanced rationales in year three (paper 3). This indicates the PSTs' dynamic purposes behind their selection of instructional strategies centered on the students. For example, they did not focus on one primary rationale, such as delivery of content to students based on knowledge of their misconceptions. This has the potential to impede student-centered teaching by filtering away other varieties of knowledge about students. However, the PSTs used a wide selection of rationales, including facilitation of student participation and application of content to students' lives. This indicated profound engagement with students' knowledge of and approaches to the science topics, indicating their progress on the learning trajectory toward an understanding of the role of students' initial ideas and experiences. Such learning progressions have been described by Schneider and Plasman (2011) as important for PCK development.

Third, evidence of student-centered teaching from the video study represents a contrast to previous studies of PSTs' classroom practice. PSTs may have the ability to actively use students' ideas about science in teaching (Thompson et al., 2013). However, most research seems to show that beginner PSTs lack an ability to focus on student learning (Kagan, 1992; Körkkö et al., 2016; Mellado, 1998) and activate students' thinking (Ratinen et al., 2015). In recent Norwegian studies, third-year science PSTs were found to have limited focus on students and their learning during planning (Juhler, 2016), particularly reflection upon physics lessons (Juhler, 2018). Based on video data from the same project, Juhler (2016) showed how second-year science PSTs focused on the subject-matter aims of the physics lessons. However, PSTs kept students in mind, driven by an intervention combining lesson study and use of a PCK-related tool for planning science lessons. Summarizing the studies in his dissertation, Juhler (2017) characterized PSTs' focus on students as mainly concerned with encouraging them to voice their ideas and helping them to give correct answers rather than probing into students' understanding.

The video evidence presented in paper 1 shows how beginner PSTs were able to notice and make use of students' ideas, approaches, and misconceptions to give student-centered teaching in several science topics. The participating PSTs were enrolled in a program for teachers for grade 5–10, like those reported in Juhler (2017). However, they had just a few months of experience in the program and were not participating in any interventions. Therefore, their student-centered teaching was notable. Further, it is interesting that the PSTs in my project had better performance in terms of student-centered teaching compared to in-service teachers (Gamlem, 2019; Gamlem & Munthe, 2014). In particular, the PSTs in the current project generally facilitated high-quality classroom discourse, while in-service mathematics teachers struggled to do so (Gamlem, 2019).

The findings discussed in this section are based on empirical evidence of how PSTs' pPCK was transformed into enacted PCK (ePCK). Classroom instruction represents PCK in action or enacted PCK (ePCK), which is a subset of a teachers' pPCK in the refined consensus model of PCK (see section 4.4). The student-centered teaching I observed on video was likely to be grounded in the integration of knowledge of students' understanding of science and knowledge of instructional strategies identified in SRIs. The relationship between pPCK and ePCK has been described in prior empirical studies (Kulgemeyer et al., 2020; Mavhunga & van der Merwe, 2020). This thesis describes how decisions made during the lesson were informed by knowledge about students, and it reveals that the rationales for using instructional strategies were nuanced.

5.2 Teaching with science in mind

In this section, I focus on the particularities of teaching science content. I discuss PSTs' abilities to communicate science content to students, followed by a discussion of their shortcomings. The PSTs taught physics (energy, fuels), astronomy (stars, the sun, northern lights, moon phases, seasons), chemistry (alcohols, oil), biology (animals, the eye, nutrients, energy content in food, drugs, sexual health, puberty, animal cells, oxygenation in lungs), and technology and design. The variety of topics makes the findings of the project relevant across science disciplines. However, this also makes it difficult to precisely capture the content aspect of PCK. This is discussed as a limitation in section 6.3. I begin the current section by discussing PSTs' success in teaching with science in mind.

First, video evidence showed how PSTs were able to effectively prompt students' prior ideas about science that were relevant to the topic at hand and to connect these ideas to new knowledge. Although some segments indicated that PSTs remained at the surface level of students' prior knowledge, in many segments, the PSTs effectively built on this knowledge. Connecting new knowledge to prior knowledge increases the chances for deep understanding of the content (Grossman et al., 2013). However, successfully making connections relies upon the teacher's understanding of CK and which connections are fruitful.

Second, in most segments, PSTs facilitated quality classroom discourse with a focus on science. To do so, they needed to not only lead students to talk together but also keep the dialogue focused on science and expand on core ideas expressed by participants. According to Scott et al. (2006), proper leadership of dialogic science classroom discourse relies on both general pedagogical principles and science-specific knowledge. The PSTs described in paper 1 acted on PK, science CK, and knowledge of instructional strategies (i.e., PCK) when leading scientific discussions. Third, the PSTs used practical activities in almost half of the segments. Most of these activities were linked to learning of science CK. In this way, students are engaged with important interplay between ideas and observations (Abrahams & Millar, 2008). Thus, the PSTs had already started to overcome a challenge faced by science teachers: manipulating ideas, not just equipment (Hofstein & Kind, 2012).

Evidence from the SRI studies (papers 2 and 3) sheds light on how PSTs took the specific features of the science subject into account in their teaching. In these studies, reflections on the use of instructional strategies were analyzed.

First, in both SRI studies, the instructional strategies discussed by the PSTs were primarily topic-specific activities, representations, and discussions. Several of the strategies were developed by the PSTs themselves, showing their ability to break down science knowledge into components that are useful for teaching and to design strategies for teaching them. Thus, PSTs relied on general pedagogical strategies to teach science to only a small degree. This result contrasts a study conducted on 43 teachers during their last year as PSTs and first year as teachers (Friedrichsen, 2015). Although PCK was in focus in her study, Friedrichsen's results showed that the teachers developed more general PK than topic-specific PCK.

Second, my analyses of PSTs' rationales for using instructional strategies contribute to the understanding of PSTs' science focus in their teaching. In year 1, the PSTs' reasons for using instructional strategies were grounded in a mix of PK and PCK (paper 2). In year three, the balance was shifted toward PCK rationales. In most analyzed segments in paper 3, PSTs based their instructional decisions on science- and topic-specific PCK rationales. This deepens the finding discussed above, showing that PSTs' instruction was not dominated by generalized patterns of instruction filled with science content. Rather, the thinking behind use of instructional strategies, often PCK strategies, was increasingly grounded in science PCK. This indicates that PSTs had an increasing ability for science-grounded decision-making three years into the program, resulting in a strengthened and enriched focus on the particularities of teaching science. Development may be caused by a sustained focus on science CK and PCK in the specialized science courses within their teacher education program. As paper 3 showed that alignment with specialized science courses resulted in even higher percentages of PCK-related rationales, these courses are probably beneficial for maintaining teaching with clear communication of science knowledge.

On the other hand, evidence also showed the beginner PSTs' shortcomings in teaching with science in mind. First, a central component of science instruction is to provide quality explanations useful for students to build sound understandings of science (Kulgemeyer et al., 2020). However, video evidence in paper 1 showed that PSTs' scientific explanations, examples, illustrations, models, and analogies were often missing, weak, or incorrect. This was particularly true in lessons that went into depth on abstract and dynamic concepts, such as nutrients, energy content in food, energy, fuels, and technology and design. Although PSTs' CK was not measured in this project, one can assume their CK of difficult topics not covered in their specialized science courses was limited. Thus, shortcomings in their science teaching should be expected.

CK has been highlighted as a major knowledge base for PCK development (Carlson et al., 2020), and research has shown that teaching strategies may collapse with a lack of sound CK (Coetzee et al., 2020). The poor representations of science content are notable because the PSTs' practical activities were focused on communicating science CK. This may indicate that it is more demanding for PSTs to explain and represent complex CK than to add a science focus to students' practical activities.

Second, a lack of knowledge of or attention to the importance of science language resulted in inconsistent use of scientific terms, often without explanation. Although consistent and clear use of subject-specific language is a crucial component of teaching (Klette et al., 2017), Juhler (2016) found that some Norwegian PSTs struggle with this.

Third, shortcomings in teaching with science in mind became evident in PSTs' unspecific feedback practices. Quality feedback addresses specific features of students' work (Gamlem & Munthe, 2014; Grossman et al., 2013) and is closely bound to the core science ideas of the lesson. In general, the participating PSTs were not able to do this.

Fourth, the PSTs' teaching involved questions and tasks with low cognitive challenge. Cognitively challenging instruction relies on sufficiently well-developed PCK for the topics being taught. This includes knowledge of students' misconceptions, on which they can be challenged; which steps are likely to help students make progress in their learning; and strategies for completing those steps (Fauth et al., 2019).

Fifth, paper 1 showed that PSTs seldom enacted inquiry teaching, even though it was emphasized in the specialized science courses. The lessons studied in paper 3 included lab sessions, but students never investigated their own questions. Inquiry teaching includes complex teaching tasks (Crawford, 2014) and relies on both profound PCK and CK to be effectively carried out (Lederman & Lederman, 2019). The almost complete absence of inquiry teaching indicates that the PSTs were at a low developmental stage in terms of inquiry teaching. This stage is characterized by a focus on the difficulties with inquiry teaching rather than providing students with opportunities to investigate their own questions (Schneider & Plasman, 2011). Prior studies of PSTs (Brown et al., 2013) and in-service teachers (Ødegaard, Kjærnsli, Karlsen, Kersting, et al., 2020) have also found inquiry teaching to be rare. This may be due to the use of a narrow definition, according to which general approaches to teaching inspired by scientific inquiry did not count as inquiry teaching. Reform-oriented science education includes inquiry teaching as a central element (Anderson et al., 1994), and inquiry is central in the Norwegian national science curriculum (Norwegian Directorate for Education and Training, 2020), which makes its absence notable.

These five points clearly show the potential for PSTs' to place sharper and deeper emphasis on clear communication of science concepts and inquiry teaching. However, it should be noted that the participants were in their first and third years of a five-year teacher education program. Their educational backgrounds varied from no science specialization in high school to two years of classes in a science discipline. Thus, they are not expected to have profound CK in the science topics to which they were assigned, and it is not expected for them to have rich knowledge of instructional strategies for all topics.

The above discussions show both how PSTs managed to convey a solid understanding of CK and their limitations in this regard. Interestingly, both findings were identified in the same material, with data sometimes based on the same science lessons. Video evidence showed that they made efforts to let the specific science content guide their teaching. The SRI studies supported this.

It is notable that the PSTs seldom shared reflections about science CK. On one hand, this indicates they did not have strong science CK for many of the topics they taught. This is an issue with the design of the teacher education program, which places limited focus on specialization in selected science disciplines. On the other hand, relevant CK was embedded in their PCK reflections. This supports a transformative view of PCK, highlighting that CK merges with PK to form PCK (see section 5.3.2).

In summary, this section has clearly identified a need for PSTs to further develop CK and knowledge of instructional strategies for science teaching. Or, there may be a need for PSTs to better facilitate knowledge exchange from CK as a knowledge base and cPCK as shared knowledge for teaching science to pPCK and, eventually, classroom teaching (i.e., ePCK).

5.3 How pedagogical content knowledge develops

In these sections, I discuss how the current thesis contributes to the understanding of how teachers develop their knowledge and practices for science teaching. First, I discuss sources of PCK, focusing on prior learning experiences and specialized science courses. Next, I discuss how my data relate to two important knowledge bases for PCK: CK and PK. Third, I focus on how quality teaching serves as evidence of knowledge exchange between PCK realms.

5.3.1 Sources of pedagogical content knowledge

My investigations enable discussion of how future PSTs can develop professional knowledge that is useful for classroom science teaching. Two findings about PCK development caught my interest: (a) PSTs construct their PCK based on a variety of experiences, including experiences prior to formal teacher education, and (b) specialized science courses can advance the development of PCK and support knowledge exchange, resulting in quality classroom teaching.

In regard to the first finding, my case study shows that PSTs brought to their teacher education CK, knowledge of instructional strategies, and knowledge of how to integrate knowledge about students into science teaching. This was the case for both PSTs with and without teaching experience.

The first round of data collection started in October 2017, less than three months after the PSTs entered the program. The PCK, PK, and teaching practices identified in papers 1 and 2 are thus likely to be constructed partly from PSTs' experiences as students in primary and secondary school. Paper 2 confirms that one-fifth of the sources of PCK and PCK integrations were from prior learning experiences, including experiences from school and informal learning. This should not be surprising, as teachers are known to build their initial teaching practices based on experiences inside and outside formal teacher education (Pettersen, 2005). However, this so-called "apprenticeship of observation" is based on experiences from both effective and ineffective teaching methods, and therefore it may conserve teaching practices (Grossman, 1990). It is challenging for PSTs to wisely make use of the resource of prior learning experiences (Juhler, 2017). In my material, however, I see little conservation. The teaching practices I observed were not characterized by out-of-date teaching strategies with reference to prior learning experiences. Rather, PSTs seemed to make use of productive learning experiences after reflecting on them. The PSTs likely had experience with a variety of teaching practices, but it seems like student-centered practices had the most impact on their own teaching. This indicates that the PSTs' reflections were guided by reform-oriented views of science teaching (see section 5.3.3).

The impact of specialized science courses on science teaching is a focus of this project due to the accumulating evidence of the central role of these courses as a source of PCK and, in turn, classroom teaching practices. As discussed in section 5.1, PSTs' integrated PCK enabled student-centered teaching. Specialized science courses were frequently mentioned as a source of this integrated PCK. Thus, specialized science courses contributed to PSTs' student-centered teaching by only a few months into the program.

The design of the teacher education program is described in section 3.2.1. More than a third of the PSTs' references to sources in paper 2 were to specialized science courses. The PSTs reported that, after a short time in the teacher education program, their focus was on students and their learning. From specialized science courses, PSTs gained knowledge about common student misconceptions, useful instructional strategies for student-centered teaching, and knowledge of how to adjust instruction to individual students' needs, among other things.

The impact of these courses is likely intertwined with the impacts of other teacher education courses, including Pedagogy and Students (P&S) and Research and Development (R&D). For example, in the R&D course, during their first week in the school practicum, PSTs were assigned an observation task focusing on one individual student. The P&S course focused on students aged 10–16 and their development, learning, and motivation (UiT The Arctic University of Norway, 2016). The findings of paper 2 indicate the prevalent role of specialized science courses; other courses were not mentioned as important sources.

Based on this finding, I performed the third sub-study to investigate how specialized science courses impacted classroom instruction. I showed that PSTs' science teaching on topics taught in prior specialized science courses was more saturated with quality PCK. In these aligned lessons, PSTs enacted more topic- and science-specific PCK-based rationales and more often drew upon knowledge of students' understanding of science to inform instruction. According to their own statements, specialized science courses supported them in developing classroom-relevant CK, knowledge about students, knowledge about topic- and science-specific strategies, and self-efficacy for science teaching. Altogether, these findings show the ways in which specialized science courses can impact classroom teaching.

Although I did not analyze the structure of the current program or others, some interesting structural differences appeared during the project. Common models for science teacher education programs are based on content courses featuring lectures in a science discipline, lab sessions, and separate science methods courses (Etkina, 2010; Kind, 2019). Such programs, though cost-effective, often provide PSTs with poorly taught CK that is of limited relevance for their future career and limited PCK for specific topics (Bergman & Morphew, 2015; Fones et al., 1999). The design of the program studied in the current project (see section 3.2.1) may represent one way of connecting university courses with teaching in schools, as Grossman et al. (2009) called for. In her opinion, one should not assume that learning about teaching practices through reading articles or writing papers is enough to prepare PSTs for classroom teaching, particularly student-centered teaching. Further, research has suggested that science courses should integrate PCK and CK (Berry et al., 2016) and focus on science teacher knowledge in relation to teaching practice, rather than on the knowledge to be conceived by PSTs (van Driel et al., 2014). My case study indicates that specialized science courses align with these suggestions.

5.3.2 Knowledge bases for pedagogical content knowledge

In this section, I discuss the knowledge bases underlying the participants' PCK and teaching practices. The specific sources of knowledge discussed in the previous section fuel PCK development with knowledge of context, science CK, and general pedagogical knowledge (PK) (Fischer et al., 2012; Sorge, Kröger, et al., 2019). Given that the data collection took place early in the first year of teacher education, it is interesting to discuss how CK and PK as knowledge bases support PCK development. Both CK and general PK have been highlighted as important knowledge bases for PCK development from early literature on the topic (Shulman, 1986, 1987) to recent publications (Kind & Chan, 2019; Sorge, Kröger, et al., 2019).

This thesis has shown that participating PSTs had PCK for the topics they taught, and they integrated knowledge of students' understanding with knowledge of instructional strategies from the first year on. This finding is notable because some of the PSTs had no specialization in science from high school and just a few months of experience in the teacher education program.

A focus on PK is more prevalent in Norway's teacher education tradition than a focus on CK (Skagen & Elstad, 2020). Research indicates that the development of effective PCK requires some science CK (Kind, 2009b; van Driel et al., 2014). Additionally, good CK is not a precursor for good PCK, and PCK development does not have to wait for strong CK (Sorge, Kröger, et al., 2019). One study indicated that PCK may be even easier to develop outside of a teacher's field of specialization (Kind, 2009a).

In the current project, however, it has not been an issue for PSTs to use deep science CK in teaching. For example, they did not struggle with explaining a complex topic in sufficiently simple terms. Rather, they operated on the edge of their own CK. This CK seemed to be tied to their PCK, supporting a transformative view of PCK. In this view, PCK is developed by combining CK, context, and pedagogy into PCK (Gess-Newsome, 1999; Kind, 2019). An integrative view of PCK would entail that teachers use CK as a separate knowledge base from PCK, ultimately merging them in the moment of teaching (Gess-Newsome, 1999). Although I could have split the knowledge shared by PSTs into context, content, and pedagogy, and PSTs probably developed these knowledge bases, the transformative view makes most sense in the current project. In my analysis of the knowledge used by the PSTs, the most precise description seemed to be PCK, rather than CK mixed with elements of PK and context knowledge. On one hand, unity of CK and PK is useful for classroom teaching, which is a motivation for including specialized science courses in teacher education. On the other hand, a separate process of CK development may be more continuous and would better prepare PSTs for a deep understanding of CK.

5.3.3 Knowledge exchanges

PCK is filtered in each knowledge exchange between realms and through the learning context (see section 2.1.2). I studied these important transitions. The long-term goal of becoming expert science teachers involves development of sound pPCK, which refers to knowledge at individual teachers' disposal to teach specific topics (Carlson et al., 2020). In their development of pPCK, teachers draw on both cPCK and ePCK. This means that experiences from both within the context of a specific classroom as well as shared knowledge about teaching and learning of science outside that context contribute to the development of a teacher's science pPCK.

Teachers' beliefs and attitudes amplify or filter knowledge exchanges (Carlson et al., 2020). Magnusson et al. (1999) represented these as science teaching orientations, which represents ways of viewing science teaching. Currently, there is no consensus on what comprises science teaching orientations (Friedrichsen et al., 2011), and they are not a main focus of the current project. However, as ideas about science teaching and learning may be extracted from teaching practice (Schneider & Plasman, 2011), my investigations can inform discussion of the PSTs' beliefs. One reasonable extrapolation based on my findings is that reform-based epistemological beliefs (Luft & Roehrig, 2007) amplified knowledge exchanges, resulting in the observed student-centered teaching (see section 5.1). Reform-based beliefs align with constructivist theories of education due to their emphasis on the students as active learners rather than the teacher as supplier of information (Anderson et al., 1994; Pettersen, 2005). They lead to an emphasis on student-centered teaching, in which students co-construct meaning with their teacher, rather than receiving finished packages of knowledge (Luft & Roehrig, 2007). It is encouraging to identify some of these reform ideas in PSTs' teaching practice.

My finding of functional knowledge exchanges contrasts a prior study, which examined how PSTs tried to enact PCK from a reform-based teacher education program (Brown et al., 2013). The authors found that, although the PSTs gained new ideas about science teaching from their teacher education program, their classroom instruction remained teacher-centered. Robust science teaching orientations shaped by background experiences were identified as a reason for filtered knowledge exchange from pPCK to ePCK.

I did not find this kind of filtering in the current project. Rather, the interview data indicate that specialized science courses formed science teaching orientations, amplifying the focus on students' learning. Further, PSTs provided instruction with clear parallels to specialized science course lessons. In terms of the refined consensus model, this means that cPCK allowed the PSTs to build pPCK that was relevant to science teaching in the classroom. Further, it was transferable to the context in which classroom teaching took place. Lastly, filters did not hinder knowledge exchange from taking place.

The findings discussed here are confirmed by Olufsen et al. (2021). Based on reports from PSTs and mentor teachers, the authors found that the quality of teaching increased when PSTs had subject specialization in a program similar to the one studied in the current project.

6 Ending remarks

6.1 Limitations

Some limitations of the study should be mentioned. First, the number of participants in the project was small. However, my aim was not to produce generalizable results, but to gain insights into individual PSTs' learning and teaching. In sub-study 2, the close attention to detail made analysis a time-consuming process, and a total of six participants was a reasonable limit. However, for the video analyses in paper 1, additional classrooms and lessons would have contributed to more robust interpretations. Additionally, of the PSTs I followed in sub-study 3, only three taught one unaligned and one aligned lesson. Thus, paper 3 was based on these three participants. The findings would have been more nuanced and stronger if they were built on additional PSTs' experiences.

Second, the participants were studied as one case, not seven individual cases. This limited the nuances I was able to discover. As discussed in section 3.1, my initial approach was at the individual level. However, the similarities I identified among participants led me to present the results as one case.

Third, I did not focus on school practicum teaching experiences as a source of PCK. Teaching experience has been found to be a major source of PCK development (Grossman, 1990; Nilsson & Loughran, 2012; Sorge, Stender, et al., 2019). From the second school practicum on, the impact of teaching experience was probably amplified by the opportunities for PSTs to reflect on their classroom teaching based on videos. Indeed, use of classroom videos is known to enhance PSTs' instruction (Johnson & Cotterman, 2015; Sun & van Es, 2015). In sub-study 2, the PSTs referenced peer PSTs and mentor teachers as sources of ePCK. However, I did not address the development of pPCK based on teaching experiences specifically. Teaching experience, or ePCK, as a source of pPCK may have caught my attention to a smaller degree than sources in the cPCK realm because the study design limited my ability to see and ask PSTs about this. In an effort to make sense of what was going on during teaching practice, the learning outcomes of the teaching practice itself remained in the background for both me and the participating PSTs.

Fourth, my use of the model of science PCK suggested by Magnusson et al. (1999) represents a limitation. I used this model to distinguish between separate components of PCK. However, scholars have argued that teachers do not organize their knowledge in silos (Friedrichsen, 2015). This is a discussion to which I have returned multiple times through the project. Recent models of PCK (Carlson et al., 2020; Gess-Newsome, 2015) do not provide frameworks of specific components of PCK. Therefore, I used the Magnusson model's categories, which are useful for the design of data collection and initial analysis (Friedrichsen, 2015).

Fifth, as more than one view of teacher learning was relevant, emphasis on one view meant that other aspects of teacher learning remained in the background. The cognitive dimension of PCK development had the most impact on the study design, at the cost of the social dimension. The research methods I used, especially SRIs, were oriented toward capturing individual PSTs' thinking and how different sources contributed to the cognitive construction of pPCK (Park, 2019). However, social learning was also evident, as PSTs referenced peer PSTs and mentor teachers as sources of PCK and PCK integrations.

Sixth, the teaching of different science topics was studied together. This is a limitation, since PCK is often seen as specific to a certain topic, or at least a certain discipline (Chan & Hume, 2019). During the design phase of the project, I intended to study PSTs' teaching of similar topics. However, the mentor teachers determined which topics PSTs would teach in school practica based on local plans and discussions with the PSTs. I decided that interrupting this process would be difficult and represent an unintended intervention. Therefore, for sub-studies 1 and 2, I decided to observe the science topics that were planned. For sub-study 3, I suggested that PSTs teach at least one of the topics covered in their previous specialized science courses and one other topic. Three of the PSTs did so.

6.2 Conclusions

The purpose of this project was to describe knowledge exchanges between cPCK, pPCK, and ePCK, especially PSTs' enactment of PCK in the context of school practica. I fulfilled this purpose by analyzing classroom video recordings and performing interviews with PSTs in which video recordings were used to prompt reconstruction of reflection-in-action from their classroom teaching.

I respond to the need for more insight into PSTs' development of science PCK and teaching practices. Specifically, researchers have pointed to a need for investigations of teaching practices in school practica beyond PSTs' self-reports (Lawson et al., 2015; Wilson et al., 2001). Others have indicated a need for insights into how PCK enables teachers to deliver quality instruction (Alonzo et al., 2020; Sorge, Kröger, et al., 2019; van Driel et al., 2014), and how teachers integrate components of PCK (Aydin et al., 2015; Chan & Hume, 2019). In responding to these calls, I followed suggestions to use SRIs to examine instructional decisions (Park, 2019; van Driel et al., 2014). I also performed a fine-grained analysis of PSTs' reflection-in-action as a basis for visualizing their integrations of the two PCK components. In terms of method, my approach represents a development of the PCK map approach introduced by Park and Chen (2012).

The first overarching research question was, "How do pre-service science teachers enact their first pieces of professional knowledge, especially PCK, in school practica?" Two answers to this question stand out. First, the video evidence showed dimensions of instructional quality, especially student-centered teaching, which facilitated students' knowledge construction. Previous studies reported contrasting findings of teacher-centered teaching (Mellado, 1998; Ratinen et al., 2015). Second, there was limited precise communication of science and inquiry teaching. This may be due to PSTs' lack of CK, knowledge of instructional strategies, or translation of such knowledge into teaching practice.

The second overarching research question was, "How do PSTs develop pPCK, and how is this knowledge transformed into ePCK during science teaching?" There are several answers to this question. First, I found that the PSTs draw mainly on PCK in their teaching. In contrast, earlier research indicated that PSTs had limited PCK (Kind, 2009b; van Driel et al., 2002) and relied on PK (Friedrichsen et al., 2009). The PSTs built pPCK from various sources, including personal learning experiences and specialized science courses. The courses impacted classroom teaching by developing PSTs' CK, PCK, and self-efficacy for science teaching. In classrooms, specialized science course experiences resulted in greater use of instructional strategies that were designed specifically for science due to PSTs' nuanced usage of PCK. Second, I found that the PSTs integrated knowledge of students with knowledge of instructional strategies, and that this integration was enhanced by specialized science courses. My finding of rich integration differs from earlier studies (Aydin et al., 2015; Juhler, 2017; Sickel & Friedrichsen, 2018).

Together, my findings contribute empirical evidence about PSTs' PCK. Via pPCK within the learning context, the PSTs were able to transform cPCK into ePCK in classroom teaching, represented by PSTs' decision-making and classroom practice. Thus, they showed an ability to put theory into action. My data support the connections outlined in the refined consensus model of PCK (Carlson et al., 2020), and explore mechanisms of functional knowledge exchange between realms.

6.3 Implications for teacher education

My case study suggests the possibility of including courses that combine CK and PCK in teacher education programs. Grossman (1990) suggested a focus on PCK development through a subject-specific approach, and Kind (2009b) suggested a transformative view of PCK in teacher education. The current thesis supports these viewpoints and shows how experiences with learning CK and PCK together in specialized science courses can directly inform classroom teaching.

Another implication for the design of teacher education is that PSTs benefit from opportunities to teach science topics that are covered by specialized content courses within teacher education, as indicated by Olufsen et al. (2021). The current thesis shows how the teaching of these topics allows PSTs to practice what they have learned and to build self-efficacy for science teaching. The literature has elucidated the usefulness of parallel science teacher education and teaching (Berry et al., 2016; Schneider & Plasman, 2011). However, if beginner PSTs are assigned complex and difficult topics to teach in classrooms, my findings indicate that they may face challenges teaching science with sufficient precision.

Participant PSTs' constructive use of prior learning experiences leads me to suggest that teacher educators should have a nuanced view on the "apprenticeship of observation." It is important to acknowledge and build on school students' prior knowledge and experiences (Grossman et al., 2013). Teacher educators should also acknowledge that beginner PSTs have years of experience from schools, including first-hand knowledge about how instruction facilitates learning and how it does not. The results of sub-study 2 support research indicating that prior teaching experience requires additional reflection to become useful for developing PCK (Friedrichsen et al., 2009; Wongsopawiro et al., 2017). For teacher educators, building upon these experiences should be seen as an efficient alternative to treating beginner PSTs as blank slates.

An important aspect of reform-oriented science education is scientific inquiry (Anderson et al., 1994; Sawada et al., 2002). It was a focus in the PSTs' specialized science courses (UiT The Arctic University of Norway, 2016), it is central in the Norwegian school curriculum (Norwegian Directorate for Education and Training, 2020), and it was a topic discussed in the school practica. However, inquiry teaching was almost absent from the lessons I studied, indicating a potential for development. My case study invites reflection on the role of inquiry teaching in school practica. Teacher educators from universities and schools should discuss how a shared vision of different components of teacher education contributes to the development of PSTs' competency in science inquiry teaching.

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Appendix

- Approval from The Norwegian Centre for Research Data (NSD)
- Letters of invitation and informed consent to pre-service teachers and students
- LISSI video observation manual

Johannes Sæleset
Institutt for lærerutdanning og pedagogikk UiT Norges arktiske universitet

9006 TROMSØ

Vår dato: 29.06.2017	Vår ref: 54397 / 3 / LB	Deres dato:	Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 11.05.2017. Meldingen gjelder prosjektet:

54397	*Utvikling av Pedagogical Content Knowledge gjennom naturfagpraksis*
Behandlingsansvarlig	*UiT Norges arktiske universitet, ved institusjonens øverste leder*
Daglig ansvarlig	*Johannes Sæleset*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvernombud/meld_prosjekt/meld_endringer.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.06.2020, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Lene Christine M. Brandt

Kontaktperson: Lene Christine M. Brandt tlf: 55 58 89 26
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Førespurnad om deltaking i forskingsprosjektet

"Naturfagstudentar si utvikling i praksisopplæringa"

Bakgrunn og formål

Dette forskingsprosjektet følger nokre lærarstudentar gjennom naturfagundervising i praksis frå første til tredje studieår. Studien skal gi svar på

- Kva studentar gjer i naturfagundervising i praksisopplæringa.
- Korleis naturfagstudentar utviklar sin didaktiske kompetanse, det vil sei kunnskap om naturfagundervising.

Du blir som student og tidlegare deltakar i prosjektet spurt om å delta igjen. Datainnsamlinga skjer i skuleåret 2019/2020. Prosjektet er ein doktorgradsstudie ved institutt for lærarutdanning og pedagogikk, UiT – Norges arktiske universitet. Du får også val om å godkjenne at data blir brukt i opplæringsformål.

Kva inneber deltaking i studien?

Det blir gjort videoopptak av naturfagundervisinga du har ansvar for i begge praksisperiodane. Etter to av desse undervisingsøktene blir du spurt om å delta eit intervju som handlar om di tenking undervegs i timen. Intervjusamtalen varar 60-70 minutt. I tillegg blir innleverte dokument knytt til praksisopplæringa teke med i studien.

Kva skjer med informasjonen om deg?

Alle personopplysingar vil bli behandla konfidensielt. Prosjektgruppa beståande av meg og tre rettleiarar vil ha tilgang til materialet. Video- og lydopptak skal lagrast kryptert og sikra mot tilgang for utanforståande. Transkript av videoopptak og intervju skal avidentifiserast og navneliste oppbevarast separat på sikker stad.

Det vil ikkje vera mogeleg å kjenna deg att i publikasjonar.

Prosjektet skal avsluttast 01.06.2023. Innan denne datoen skal datamaterialet anonymiserast, og lyd- og videoopptak slettast, med mindre du gir samtykke til at videoopptak lagrast vidare til bruk i undervisingsføremål. Video vert då lagra utan tilgang for uvedkomande og slettast seinast 01.06.2032.

Frivillig deltaking

Det er frivillig å delta i studien, og du kan når som helst trekkje ditt samtykke utan å oppgi nokon grunn. Dersom du trekkjer deg, vil alle opplysingar om deg bli anonymisert. Det vil ikkje ha innverknad på ditt studieløp eller andre forhold dersom du ikkje vil delta i studien eller seinare vel å trekkja deg.

Dine rettar

Så lenge du kan identifiserast i datamaterialet, har du rett til:

- innsyn i kva personopplysingar som er registrert om deg
- å få retta personopplysingar om deg
- å få sletta personopplysingar om deg
- få utlevert ein kopi av dine personopplysingar (dataportabilitet), og
- å sende klage til personvernombodet eller Datatilsynet om behandlinga av dine personopplysingar

Kva gir oss rett til å behandla personopplysingar om deg?

Vi behandlar opplysingar om deg basert på ditt samtykke.

På oppdrag frå UiT Noregs arktiske universitet har NSD – Norsk senter for forskningsdata AS vurdert at behandlinga av personopplysningar i dette prosjektet er i samsvar med personvernregelverket.

Kvar kan eg finne ut meir?
Om du har spørsmål til studien, eller ynskjer å nytte deg av dine rettar, ta kontakt med:
- UiT Noregs arktiske universitet ved PhD-student Johannes Sæleset.
Tlf: 776 60 309/901 49 686. E-post: johannes.saleset@uit.no.
- Vårt personvernombod: Joakim Bekkevold. Tlf 776 46 322. E-post: personvernombud@uit.no
- NSD – Norsk senter for forskningsdata AS. E-post: personverntjenester@nsd.no. Tlf: 55 58 21 17

Dersom du ynskjer å delta i studien kan du gi ditt samtykke ved å signera under.

Samtykke til deltaking i studien

Eg har motteke informasjon om studien, og er villig til å delta

----
(Signert av prosjektdeltakar, dato)

OG

Kryss av her dersom du i tillegg vil gi samtykke til at

☐ Videoopptak kan brukast til opplæringsføremål, også etter at prosjektet er avslutta

Førespurnad om deltaking i forskingsprosjektet

"Naturfagstudentar si utvikling i praksisopplæringa"

Bakgrunn og formål
Dette forskingsprosjektet følger nokre lærarstudentar gjennom naturfagundervising i praksis frå første til tredje studieår. Studien skal gi svar på

- Kva studentar gjer i naturfagundervising i praksisopplæringa.
- Korleis naturfagstudentar utviklar sin didaktiske kompetanse, det vil sei kunnskap om naturfagundervising.

Ditt barn er elev i ein klasse som får praksisstudentar frå lærarutdanninga i naturfag skuleåret 19/20. Du blir her spurt om godkjenning til opptak av video i naturfagtimane.
Prosjektet er ein doktorgradsstudie ved institutt for lærarutdanning og pedagogikk, UiT – Norges arktiske universitet. Du får også val om å godkjenne at data blir brukt i opplæringsformål.

Kva inneber deltaking i studien?
Det vil bli gjort videoopptak av studentane si naturfagundervising i praksis hausten 2019 og våren 2020.

- Formålet med filminga er å få opptak av praksisstudentane si undervising.
- Ditt barn kan bli med på videoopptaka, men er ikkje fokus i prosjektet.

Kva skjer med informasjonen om ditt barn?
Alle personopplysingar vil bli behandla konfidensielt. Prosjektgruppa beståande av meg og tre rettleiarar vil ha tilgang til materialet. Video- og lydopptak skal lagrast kryptert og sikra mot tilgang for utanforståande. Avskrift av videoopptak og intervju skal avidentifiserast og namneliste oppbevarast separat på sikker stad.

Det vil ikkje vera mogeleg å kjenna att deltakarane i studien i forskingsartiklar eller andre publikasjonar.

Prosjektet skal avsluttast 01.06.2023. Innan denne datoen skal datamaterialet anonymiserast, og lyd- og videoopptak slettast, med mindre du samtykker til at videoopptak lagrast vidare til bruk i undervisingsføremål. Video vert då lagra utan tilgang for uvedkomande og slettast seinast 01.06.2032.

Frivillig deltaking
Det er frivillig å delta i studien, og du kan når som helst trekkje ditt samtykke utan å oppgi nokon grunn. Dersom du trekkjer samtykket, vil alle opplysingar om ditt barn bli anonymisert. Det vil ikkje ha innverknad på skulegangen eller andre forhold dersom du ikkje vil delta i studien eller seinare vel å trekkja samtykket.

Dine rettar
Så lenge du kan identifiserast i datamaterialet, har du rett til:
- innsyn i kva personopplysingar som er registrert om ditt barn
- å få retta personopplysingar om ditt barn
- å få sletta personopplysingar om ditt barn
- få utlevert ein kopi av dine personopplysingar (dataportabilitet), og
- å sende klage til personvernombodet eller Datatilsynet om behandlinga av dine personopplysingar

Kva gir oss rett til å behandla personopplysingar om ditt barn?
Vi behandlar opplysingar om ditt barn basert på ditt samtykke.

På oppdrag frå UiT Noregs arktiske universitet har NSD – Norsk senter for forskningsdata AS vurdert at behandlinga av personopplysningar i dette prosjektet er i samsvar med personvernregelverket.

Kvar kan eg finne ut meir?
Om du har spørsmål til studien, eller ynskjer å nytte deg av dine rettar, ta kontakt med:
- UiT Noregs arktiske universitet ved PhD-student Johannes Sæleset.
Tlf: 776 60 309/901 49 686. E-post: johannes.saleset@uit.no.
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- NSD – Norsk senter for forskningsdata AS. E-post: personverntjenester@nsd.no. Tlf: 55 58 21 17

Dersom du ynskjer å delta i studien kan du gi ditt samtykke ved å signera under.

Samtykke til deltaking i studien

Namn på elev:

Eg har motteke informasjon om studien og gir fylgjande svar på førespurnaden:
☐ Mitt barn kan delta i studien
☐ Mitt barn kan <u>ikkje</u> delta i studien

(Signert av føresett, dato)

OG

Kryss av her dersom du i tillegg vil gi samtykke til at

☐ Videoopptak kan brukast til opplæringsføremål, også etter at prosjektet er avslutta

LISSI video observation manual

Ødegaard, M., Kjærnsli, M., Karlsen, S., Lunde, M. L. S., Narvhus, E. K., Olufsen, M., & Sæleset, J. (2020). *Linking Instruction in Science and Student Impact (LISSI) observasjonsmanual for naturfagundervising* [Linking Instruction in Science and Student Impact (LISSI) observation manual for science instruction]. University of Oslo. https://www.uv.uio.no/ils/forskning/posjekter/lissi-laring-naturfag/

Categories used in the current project are described in English in table 3 at page 40-41.

LISSI OBSERVASJONSMANUAL

for naturfagsundervisning

Observasjonsmanualen ble utviklet av forskere på LISSI-prosjektet, et prosjekt med formål å undersøke sammenhengen mellom undervisning i naturfag og hvordan elevene lærer og engasjerer seg i faget.

Prosjektet er finansiert av Utdanningsdirektoratet

Av:

Marianne Ødegaard (prosjektleder)

Marit Kjærnsli

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Magne Olufsen

Johannes Sæleset

Utdanningsdirektoratet

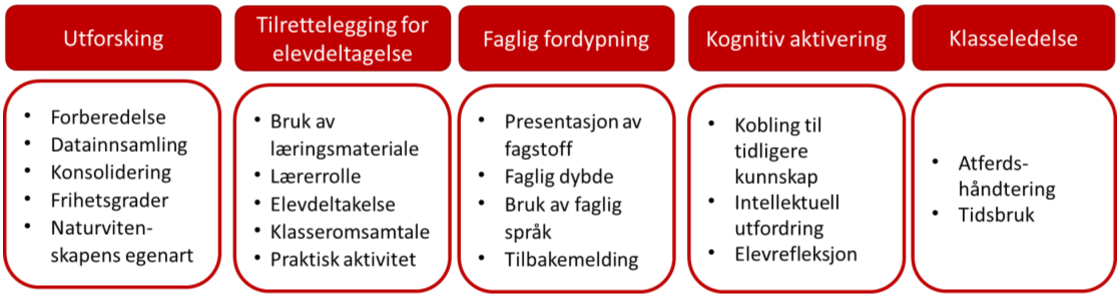
UiO : Institutt for lærerutdanning og skoleforskning
Det utdanningsvitenskapelige fakultet

UiT Norges arktiske universitet

Introduksjon

En sentral metode i forskningsprosjektet Linking Instruction in Science and Student Impact (LISSI) er analyse av videoopptak av naturfagundervisning i norsk skole. Denne observasjonsmanualen ble utviklet med det formål å analysere slike videodata. Utgangspunktet for LISSI-prosjektet var å studere utforskende arbeidsmåter i naturfag, men observasjonsmanual retter seg også mot generelle undervisningspraksiser i klasserommet. Manualen er basert delvis på eksisterende observasjonsmanualer for undervisningskvalitet (Grossman, Loeb, Cohen & Wyckoff, 2013; Marshall, Horton & White, 2009; Ødegaard, Haug, Mork & Sørvik, 2016), og inneholder kategorier fra disse manualene (referanser er notert til hver kategori). Noen av kategoriene er beholdt i sin opprinnelige form, men de fleste er modifisert for å kunne beskrive naturfagundervisning.

Kategoriene er organisert i fem dimensjoner av undervisning. De fem dimensjonene er utforsking, tilrettelegging for elevdeltakelse, faglig fordypning, kognitiv aktivering og klasseledelse. Observasjonsmanualen er organisert på følgende måte:



Utforsking
- Forberedelse
- Datainnsamling
- Konsolidering
- Frihetsgrader
- Naturviten-skapens egenart

Tilrettelegging for elevdeltagelse
- Bruk av læringsmateriale
- Lærerrolle
- Elevdeltakelse
- Klasseromsamtale
- Praktisk aktivitet

Faglig fordypning
- Presentasjon av fagstoff
- Faglig dybde
- Bruk av faglig språk
- Tilbakemelding

Kognitiv aktivering
- Kobling til tidligere kunnskap
- Intellektuell utfordring
- Elevrefleksjon

Klasseledelse
- Atferds-håndtering
- Tidsbruk

Når undervisning analyseres, gis kategoriene koder som beskriver undervisningskvalitet i hver kategori. Bruk av observasjonsmanualen baseres på 15-minutters undervisningssegmenter. Hvert segment vurderes opp mot alle kategoriene, som kodes fra 1-4. Kode 1 viser til ingen bevis for den aktuelle praksisen, kode 2 begrensede bevis, kode 3 viser bevis, men med noen begrensninger og kode 4 indikerer sterke bevis. Kode 3 og 4 beskriver altså en høyere undervisningskvalitet enn kode 1 og 2. Noen kategorier kodes i underkategorier som slås sammen til en samlet kode. Siden hver kategori har fokus på enkeltelementer av undervisningskvalitet, er det ikke forventet at enhver undervisningstime skal oppnå høy kode i alle kategorier. Vi vil understreke at god undervisning kommer i ulike former, som også er avhengig av konteksten.

1. Utforsking

Denne dimensjonen består av fem kategorier*: forberedelse, datainnsamling, konsolidering, frihetsgrader og naturvitenskapens egenart*. De tre første tilsvarer viktige faser i utforskende undervisning. I forberedelsesfasen vekkes elevenes undring, det stilles spørsmål og utforskingen planlegges. I datainnsamlingsfasen samler elevene data fra primære og sekundære kilder (egne observasjoner eller andres observasjoner/kunnskap). I konsolideringsfasen bygger elevene kunnskap på bakgrunn av innsamlede data. Disse kategoriene er utviklet spesifikt rettet mot utforskende undervisning i naturfag og for å kunne fange opp naturvitenskapens egenart. Kategoriene er egenutviklede med basis i litteraturen.

<table>
<tr><th colspan="2">Forberedelse</th></tr>
<tr><td colspan="2">Kategorien fokuserer på forberedelsesfasen i utforskende undervisning. Her legger læreren til rette for utforsking ved å vekke undring, og elever eller lærer stiller spørsmål, lager hypotese eller prediksjon.

Undervisning som gis lav kode, kan inneholde undringsaktiviteter, men det blir ikke utviklet en prediksjon, en hypotese eller et forskbart spørsmål. <i>Forberedelse</i> gis høy kode dersom lærer eller elever utvikler et forskbart spørsmål, en hypotese eller en prediksjon som skal utforskes.
Ref.: Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook & Landes (2006), Knain & Kolstø (2011) og Ødegaard et al. (2016).</td></tr>
<tr><td>Kode 1</td><td>Undervisningen inneholder ikke undringsaktiviteter, prediksjoner, hypotesedannelse, forskbart spørsmål eller aktivering av forkunnskaper.</td></tr>
<tr><td>Kode 2</td><td>Lærer initierer undringsaktiviteter eller aktiverer elevenes forkunnskaper. Det blir ikke utviklet en prediksjon, en hypotese eller et forskbart spørsmål.</td></tr>
<tr><td>Kode 3</td><td>Lærer eller elever utvikler et forskbart spørsmål, en hypotese eller en prediksjon.
Eller
Elevene planlegger en utforsking basert på et forskbart spørsmål, en hypotese eller en prediksjon som er gitt av lærer eller andre.</td></tr>
<tr><td>Kode 4</td><td>Elevene planlegger en utforsking basert på deres egne forskbare spørsmål, hypoteser eller prediksjoner.</td></tr>
</table>

<table>
<tr><th colspan="2">Datainnsamling</th></tr>
<tr><td colspan="2">Kategorien fokuserer på datainnsamlingsfasen i utforskende undervisning. Her gjør elevene observasjoner eller henter informasjon fa ulike kilder.

Undervisning som gis lav kode, inneholder ikke datainnsamling, eller data samles inn uten et forskbart spørsmål, en hypotese eller en prediksjon som grunnlag. <i>Datainnsamling</i> gis høy kode dersom elever samler inn, dokumenterer og systematiserer data for å finne svar på et forskbart spørsmål, en hypotese eller en prediksjon.
Ref.: Bybee et al. (2006), Knain & Kolstø (2011) og Ødegaard et al. (2016).</td></tr>
<tr><td>Kode 1</td><td>Elevene samler ikke inn data.</td></tr>
<tr><td>Kode 2</td><td>Elevene samler inn data. Et forskbart spørsmål, en hypotese eller en prediksjon trenger ikke å være til stede.</td></tr>
<tr><td>Kode 3</td><td>Elevene samler inn data for på finne svar på et forskbart spørsmål, en hypotese eller en prediksjon. Dataene blir dokumentert.</td></tr>
<tr><td>Kode 4</td><td>Elevene samler inn data for på finne svar på et forskbart spørsmål, en hypotese eller en prediksjon. Dataene blir dokumentert og systematisert.
Eksempel: Å lage en tabell er en form for systematisering eller kategorisering av data.</td></tr>
</table>

Konsolidering

Kategorien fokuserer på konsolideringsfasen i utforskende undervisning. Her lager elevene forklaringer og trekker slutninger på bakgrunn av innsamlede data, og diskuterer implikasjoner elevene observasjoner eller henter informasjon fa ulike kilder.

I undervisning som gis lav kode, diskuterer elevene ikke data, eller lager bare enkle forklaringer. *Konsolidering* gis høy kode dersom elevene trekker konklusjoner fra data, og diskuterer implikasjoner.
Ref.: Bybee et al. (2006), Knain & Kolstø (2011) og Ødegaard et al. (2016).

Kode 1	Elevene diskuterer ikke observasjoner eller data.
Kode 2	Elevene lager enkle beskrivelser basert på observasjoner eller data. Eksempel: Bønnene falt av på papiret med vann og salt, men ikke på papiret med mel og vann.
Kode 3	Elevene trekker konklusjoner fra data. De begrunner ut fra empiriske data. Eksempel: Lim av mel og vann fungerer bedre enn lim av salt og vann fordi bønnene ikke faller av mel og vann-papiret.
Kode 4	Elevene trekker konklusjoner fra data og diskuterer disse opp mot naturfaglig kunnskap og/eller diskuterer implikasjoner av konklusjonene Eksempel: Lim av mel og vann fungerer bedre enn lim av salt og vann på grunn av at glutenet i melet gjør limet klissete.

Frihetsgrader

Kategorien fokuserer på graden av frihet i aktiviteten eller utforskingen elevene holder på med. Et sentralt element er om elevene har anledning til å planlegge eksperimenter eller finne egne spørsmål å utforske. Kategorien omfatter også i hvor stor grad resultatene er gitt på forhånd eller er kjent for læreren.

I undervisning som gis lav kode, tar elevene få valg i undervisningen. I undervisning med høy kode bestemmer elevene minst to av følgende momenter: problemstilling eller spørsmål som skal undersøkes, metode som brukes for å finne svar og resultat eller svar.
Ref.: Gyllenpalm, Wickman & Holmgren (2010) og Herron (1971).

Kode 1	Undervisningen har ikke elementer som innebærer at elevene tar valg (spørsmålsformulering, bruk av metoder eller tolkning av resultater).
Kode 2	Det er én frihetsgrad. Elevene bestemmer selv ett av følgende momenter: Problemstilling eller spørsmål som skal undersøkes. Metode som brukes for å finne svar. Resultat eller svar (elevene vet ikke resultatet på forhånd).
Kode 3	Det er to frihetsgrader. Elevene bestemmer selv to av følgende momenter: Problemstilling eller spørsmål som skal undersøkes. Metode som brukes for å finne svar. Resultat eller svar (elevene vet ikke resultatet på forhånd)
Kode 4	Elevene bestemmer selv alle de tre følgende momenter: Problemstilling eller spørsmål som skal undersøkes. Metode som brukes for å finne svar. Resultat eller svar (elevene vet ikke resultatet på forhånd).

Naturvitenskapens egenart

Kategorien fokuserer på om læreren inkluderer aspekter av naturvitenskapens egenart (NOS) i segmentet. Åtte aspekter som kan kjennetegne naturvitenskapen er inkludert her.

To aspekter gjelder grunnleggende skiller i naturvitenskapen: Skillet mellom observasjon og slutning og mellom teori og lov.
Fem aspekter gjelder kjennetegn ved naturvitenskapelig kunnskap: 1) slik kunnskap er empirisk begrunnet (basert på og/eller avledet fra observasjoner av naturen), 2) naturvitenskap involverer nødvendigvis resonnering, kritisk tenkning, fantasi og kreativitet (involverer å komme med nye forklaringer), 3) naturvitenskap er foreløpig (i endring), 4) naturvitenskap er subjektivt (teoristyrt), og 5) naturvitenskap er sosialt og kulturelt påvirket (naturvitere er påvirket av sosiale strukturer, maktstrukturer, politikk, sosioøkonomiske faktorer, filosofi og religion).
Ett aspekt gjelder enhet mellom de ulike naturfagene (fysikk, kjemi, biologi, geologi etc.). Dette aspektet fremhever integrering av kunnskap på tvers av naturfagene (kobler uttrykkelig sammen naturfagdisiplinene utover å undervise emner som relaterer til flere disipliner).

I undervisning som gis lav kode for naturvitenskapens egenart inkluderer læreren ingen aspekter av naturvitenskapens egenart eksplisitt i undervisningen. Naturvitenskapens egenart gis høy kode dersom læreren refererer eksplisitt til minst ett aspekt av naturvitenskapens egenart på en måte som gir elevene forståelse for naturvitenskapens egenart.
Ref.: Lederman, Lederman & Antink (2013).

Kode 1	Lærer inkluderer ikke aspekter av naturvitenskapens egenart.
Kode 2	Lærer inkluderer minst ett aspekt av naturvitenskapens egenart i undervisningen. Aspektene er likevel **ikke referert til eksplisitt.** Likevel, med slik undervisning over tid vil elevene utvikle forståelse av naturvitenskapens egenart. Eksempel: Utforsking uten at læreren uttrykkelig legger vekt på verdien av datainnsamling (empirisk begrunnet).
Kode 3	Lærer **refererer eksplisitt** til minst ett aspekt av naturvitenskapens egenart i undervisningen. Koblinger mellom naturvitenskapens egenart og dagens time er klar nok til å **gi forståelse** av naturvitenskapens egenart. Eksempel: Utforsking med uttrykkelig oppmerksomhet på nødvendigheten av empiriske bevis for å konkludere i et argument, og at naturvitenskapens egenart dermed har et subjektivt aspekt.
Kode 4	Lærer **refererer eksplisitt** til minst ett aspekt av naturvitenskapens egenart i undervisningen. Koblinger mellom naturvitenskapens egenart og dagens time er klar nok til å **gi dyp forståelse** av naturvitenskapens egenart. **Elevene viser forståelse** av naturvitenskapens egenart. Eksempler: - Sier noe selv om at de jobber som forskere - Viser i prosessen at dette er en forskerprosess - Elevene uttrykker forståelse av hvordan de har brukt sine data til å forklare et begrep eller fenomen, og sammenligner dette med hvordan naturvitenskaplig utforsking blir utført - Læreren legger vekt på behovet for kreative løsninger i introduksjonen til utforsking, og snakker om forskere som kreative.

2. Tilrettelegging for elevdeltakelse

Denne dimensjonen består av seks kategorier: b*ruk av læringsmateriale, lærerrolle, elevdeltakelse, tilbakemeldinger, klasseromssamtale og praktisk aktivitet*. Disse kategoriene fokuserer på hvordan læreren legger til rette for at elevene kan delta aktivt i undervisningen. Det er i hovedsak hvordan læreren gjennomfører aktiviteter som spiller inn på kodingen, men i kategorien *elevdeltakelse* vurderes elevene isolert fra læreren.

Bruk av læringsmateriale	
Kategorien fokuserer på om læreren legger til rette for at elevene deltar i aktiviteter og diskusjoner som er basert på læringsmateriale. Eksempler på læringsmateriale: objekter, lærebøker, arbeidsark, diagrammer, nettsider, videoer, tavle, smarttavle eller annet undervisningsmateriale. **I undervisning som kodes høyt for *bruk av læringsmateriale,* bruker læreren materialet til å oppnå et større mål: at elevene skal få høy naturfaglig kompetanse. Elevene bruker læringsmaterialet aktivt over lenger tid for å fordype seg i naturfaglige begreper. I undervisning som kodes lavt for *bruk av læringsmateriale,* er det ikke læringsmateriale til stede, eller det er ikke i bruk.** **Modifisert etter PLATO (Grossman et al., 2013).**	
Kode 1	Det er ikke læringsmateriale til stede i klasserommet, eller det er ikke i bruk.
Kode 2	Det er læringsmateriale til stede i klasserommet. Elevers referanser til materialet fokuserer på gjengivelse av spesifikke detaljer**.** Eksempel: Læreren viser en film. Etter at filmen er ferdig, ber læreren elevene om å fortelle læringspartner hva de har sett (gjengivelse).
Kode 3	Læreren legger til rette for undervisningsaktiviteter eller diskusjoner som krever at elever aktivt bruker læringsmateriale. Elevene må bruke læringsmaterialet til å finne grunnlag for spesifikke faglige momenter, og på denne måten bruke materialet til å danne seg en forståelse av naturfaglige begreper og fenomener. Eksempel: Læreren viser en film. Etter at filmen er ferdig, ber læreren elevene om å trekke slutninger eller forklare det de har sett.
Kode 4	Læreren legger til rette for undervisningsaktiviteter eller diskusjoner som krever at elever aktivt bruker læringsmateriale over en lengre periode (mer enn 7 minutter). Elevene må bruke læringsmaterialet til å finne grunnlag for spesifikke faglige momenter, og på denne måten bruke materialet til å danne seg en forståelse av naturfaglige begreper og fenomener.

<table>
<tr><th colspan="2">Lærerrolle</th></tr>
<tr><td colspan="2">Kategorien fokuserer på lærerens tilrettelegging for elevaktiviteter og samtaler mellom elever.

Undervisning der læreren står i fokus kodes lavt. Undervisning gis høy kode dersom læreren ofte legger til rette for elevaktivitet eller samtale mellom elever.
Ref.: EQUIP (Marshall et al., 2009).</td></tr>
<tr><td>Kode 1</td><td>Det er læreren som står i fokus i timen. Det er sjeldent at læreren legger til rette for elevaktiviteter eller samtaler mellom elever.</td></tr>
<tr><td>Kode 2</td><td>Det er læreren som står i fokus i timen. Det er av og til at læreren legger til rette for elevaktiviteter eller samtaler mellom elever.</td></tr>
<tr><td>Kode 3</td><td>Læreren legger til rette for elevaktiviteter eller samtaler mellom elever i minst tre tilfeller.</td></tr>
<tr><td>Kode 4</td><td>Læreren legger gjennomgående og effektivt til rette for elevaktiviteter eller samtaler mellom elever. Halve segmentet inneholder samtaler mellom elever, eller elevene arbeider sammen for å løse en oppgave.</td></tr>
</table>

<table>
<tr><th colspan="2">Elevdeltakelse</th></tr>
<tr><td colspan="2">Kategorien fokuserer på elevenes deltakelse i aktiviteter: I hvilken grad elever er aktive eller passive, i hvilken grad elever deltar i flere aktiviteter, og hvor mange elever som er aktive. Aktiviteter kan være elevøvelser, diskusjoner og andre oppgaver.

Undervisning der elevene stort sett er passive, kodes lavt. Undervisning gis høy kode dersom elevene er aktive i sin læring.
Ref.: EQUIP (Marshall et al., 2009).</td></tr>
<tr><td>Kode 1</td><td>Elever er gjennomgående passive i sin læring (de tar notater, leser). Elever er bare mottakere uten å delta aktivt.</td></tr>
<tr><td>Kode 2</td><td>Elever er i liten grad aktive i sin læring. De er aktive i korte stunder eller i liten grad gjennom segmentet.</td></tr>
<tr><td>Kode 3</td><td>Elever er aktive i sin læring. De er involvert i diskusjoner, undersøkelser eller andre aktiviteter, men ikke gjennomgående og tydelig fokusert.</td></tr>
<tr><td>Kode 4</td><td>Elever er gjennomgående aktive i sin læring. De er svært aktive flere ganger gjennom segmentet og tydelig fokusert på oppgaven.</td></tr>
</table>

Klasseromssamtale		
Kategorien fokuserer på elevenes muligheter for utvidete naturfaglige samtaler med lærer eller med medelever, og i hvilken grad lærer og elever plukker opp, bygger videre på og avklarer hverandres ideer. ***Klasseromssamtale* kodes lavt når læreren snakker mesteparten av tiden. *Klasseromssamtale* kodes også lavt dersom lærer eller elever responder sjelden eller kort på elevinnspill. I slik klasseromssamtale bygger ikke lærer og elever på hverandres innspill. *Klasseromssamtale* kodes på høyt nivå når elevene er engasjert i utdypende, sammenhengende og fokuserte diskusjoner hvor lærer og elever bygger på hverandres bidrag og oppfordrer hverandre til å forklare og beskrive sine ideer nærmere.** **Ref.: PLATO (Grossman et al., 2013).**		
Underkategorier	**Opptak av elevinnspill**	**Mulighet for elevsamtale**
Kode 1	Lærer eller elever responderer sjelden eller aldri på elevers innspill om naturfaglig innhold.	Det er få eller ingen muligheter for elever å ha samtaler knyttet til naturfag. Lærer snakker, gir en lang introduksjon til en oppgave/aktivitet, eller lukket diskusjon i mindre enn 5 minutter.
Kode 2	Lærer eller elever responderer kort og overflatisk på elevers innspill, og responsen bidrar ikke til å utdype eller utvikle innspillene (f.eks. gjentar uten bruk av faglig språk, kun uttalelser som «Jeg er enig/uenig», som ikke refererer spesifikt til et tidligere innspill). Alternativt responderer lærer i hovedsak kort og overflatisk på elevinnspill, ispedd enkelte tilfeller av opptak på høyere nivå.	Det finnes enkelte muligheter for korte naturfaglige elevsamtaler, men disse er lærerstyrte. For eksempel lukket diskusjon i mer enn 5 minutter, eller åpen diskusjon (i hel klasse, grupper, par) i mindre enn 5 minutter.
Kode 3	Lærer eller elevers bidrag har likevekt mellom korte responser og minimum 2 tilfeller med opptak på høyt nivå (f.eks. gjentagelse med faglig språk, spør etter forklaring, utdyping eller bevis). Det er mange tilfeller hvor lærer eller elever tar opp elevers innspill	Lærer gir mulighet for minst 5 minutter naturfaglig samtale mellom lærer og elever og/eller mellom elever. Noen elever deltar i samtalen og/eller lytter aktivt, men det er kun 2-3 elever som primært er deltakende. Det kan fortsatt være overvekt av lærerstyrt samtale med noen åpne spørsmål. Elevstyrte samtaler som etter hvert sporer av hører også til dette nivået.
Kode 4	Lærer eller elever gjør gjennomgående opptak av elevenes innspill ved å respondere på måter som bygger ut elevenes ideer, eller legge til rette for at elever utvider, forklarer og spesifiserer tenkningen sin.	Lærer gir mulighet for minst 5 minutter naturfaglig samtale mellom lærer og elever og/eller mellom elever. Flesteparten av elevene deltar i samtalen og/eller lytter aktivt, og elevene responderer på hverandres utsagn/ideer, selv om det fortsatt er læreren som styrer samtalen. Spørsmålene som styrer samtalen er hovedsakelig åpne, og samtalen er fokusert og på rett spor.

<table>
<tr><th colspan="2">Praktisk aktivitet</th></tr>
<tr><td colspan="2">Kategorien fokuserer på om undervisningen inneholder praktiske aktiviteter der elevene bruker objekter utover materiale til lesing og skriving. Eksempler på praktiske aktiviteter er rollespill og forsøk.

Undervisning gis lav kode dersom elevene kun er involvert i aktiviteter der elevene bruker materiale til lesing og skriving, slik som bøker, papir, skrivesaker eller datamaskiner. Praktiske aktiviteter som knyttes eksplisitt til læring av naturfaglige begreper, gis en høy kode.
Ref.: Abrahams & Reiss (2012); Millar (2010).</td></tr>
<tr><td>Kode 1</td><td>Elevene deltar ikke i aktiviteter som inneholder praktiske aktiviteter eller aktivitetene er begrenset til bruk av materiale til lesing og skriving.
Eksempel: Elevene leser på en nettside om biologisk mangfold.</td></tr>
<tr><td>Kode 2</td><td>Elevene deltar i aktiviteter der de bruker objekter utover materiale til lesing og skriving. Aktivitetene er imidlertid ikke eksplisitt knyttet til læring av naturfaglige begreper.
Eksempel: Elevene gjør klart utstyr for et eksperiment, eller henter ut en mineralsamling til pultene sine uten å få noen faglige instruksjoner eller diskuterer det de ser.</td></tr>
<tr><td>Kode 3</td><td>Elevene deltar i undervisningsaktiviteter der de bruker objekter utover de som trengs til lesing og skriving. Aktivitetene er eksplisitt knyttet opp mot læring av naturfaglige begreper.
Eksempel: Elevene blir bedt om å hoppe opp og ned for å forbrenne energien i et flak potetgull.</td></tr>
<tr><td>Kode 4</td><td>Elevene er involvert i undervisningsaktiviteter der de bruker objekter utover de som trengs til lesing og skriving.
Aktivitetene er eksplisitt knyttet opp mot læring av naturfaglige begreper og det kommer frem at elevene knytter aktiviteten til læringen.
Eksempel: Elevene blir bedt om å hoppe opp og ned for å forbrenne energien i et flak potetgull og diskuterer hvordan potetgullflaket blir forbrennes i kroppen.</td></tr>
</table>

3. Faglig fordypning

Denne dimensjonen består av fire kategorier: *presentasjon av fagstoff, faglig dybde, bruk av faglig språk og tilbakemelding*. Disse kategoriene fokuserer på hvordan læreren formidler kunnskap om faglige begreper til elevene. Faglige begreper inkluderer naturfaglige begreper og fenomener, begreper på utstyr og forskerord. Kategorien faglig dybde berører også elevenes kunnskap.

Presentasjon av fagstoff	
Kategorien fokuserer på hvordan læreren presenterer det naturfaglige fagstoffet i timen. Fokus er om fagstoffet presenteres korrekt og forståelig for elevene. *Presentasjon av fagstoff* er basert på Lee Shulmans (1987) begrep pedagogical content knowledge (PCK), som beskriver læreres kunnskap om hvordan spesifikke tema presenteres på en forståelig måte. Dette inkluderer kunnskap om gode representasjoner og hva som gjør temaet lett eller vanskelig. *Presentasjon av fagstoff* omfatter lærerens evne til å formidle fagstoff gjennom hensiktsmessige forklaringer, eksempler, illustrasjoner, modeller og analogier. Kun presentasjon som er observerbar skal vurderes. (Bøker og arbeidsark som ikke diskuteres skal ikke vurderes.) Både presentasjon for hele klassen og i dialog med enkeltelever og grupper er relevant for kodingen. **_Presentasjon av fagstoff_ gis lav kode når læreren ikke presenterer fagstoff, eller presentasjonen har feil eller mangler. Når læreren gir nyanserte, klare presentasjoner og hjelper elever til å skille mellom begreper og tema som er forskjellige, gis en høy kode.** **Ref.: PLATO (Grossman et al., 2013).**	
Kode 1	Læreren presenterer ikke fagstoff, eller presentasjonen er preget av feil og mangler.
Kode 2	Lærerens presentasjon er ufullstendig eller overfladisk, og går ikke i dybden av fagstoffet. Representasjonene fungerer kun delvis for å belyse begrepet.
Kode 3	Lærerens presentasjon er korrekt og presis, og er tilstrekkelig for å belyse naturfaglige begreper. Læreren kan også oppklare eventuelle misforståelser hos elever, men legger ikke vekt på å nyansere begreper eller komme med eksempler for å skille mellom ulike sider ved relaterte begreper.
Kode 4	Lærerens presentasjon er korrekt og presis, og oppklarer elevers misforståelser. Læreren belyser nyanser ved ulike begreper og tema, gjerne med ulike eksempler og modeller, eller ved å legge vekt på å nyansere begreper eller komme med eksempler for å skille mellom ulike sider ved relaterte begreper.

Faglig dybde

Kategorien er todelt og består av lærerpresentasjon og elevkunnskap. Lærerpresentasjon fokuserer på om læreren presenterer fagstoffet med dybde, og om det settes i en større sammenheng. Elevkunnskap fokuserer på hvordan elever viser sin kunnskap.

Lærerpresentasjon gis lav kode når fagstoffet presenteres overfladisk. Dersom læreren presenterer fagstoffet med dybde og i sammenheng, kan det gis en høy kode. Elevkunnskap gis en lav kode når elevene viser lite eller overfladisk kunnskap. Høy kode for elevkunnskap kan gis når elevene vise forståelse for begreper i sammenheng.
Ref.: EQUIP (Marshall et al., 2009); Bravo, Cervetti, Hiebert & Pearson (2008); Haug & Ødegaard (2014).

Underkategorier	Lærerpresentasjon	Elevkunnskap
Kode 1	Fagstoffet presenteres bare overfladisk.	Elevene viser kunnskap om hvordan begreper høres eller ser ut. Fagbegreper uttrykkes ikke nødvendigvis av elever.
Kode 2	Læreren presenterer til en viss grad faglig dybde, men setter ikke fagstoffet i en større sammenheng.	Elevene viser at de kjenner til eller kan definere naturfaglige begreper på et generelt nivå. Elevene viser liten forståelse for begrepenes betydning.
Kode 3	Læreren presenterer faglig dybde og setter fagstoffet delvis i en større sammenheng.	Elevene viser forståelse for sammenhengen mellom det aktuelle begrepet og andre ord og begreper. Eller: Elevene er i stand til å velge korrekte begreper i en kontekst. De kan bruke fagbegreper i ulike setninger.
Kode 4	Læreren presenterer faglig dybde og setter fagstoffet klart og tydelig i en større sammenheng.	Minst to elever bruker begreper i en kontekst når de arbeider utforskende. De setter begrepene i sammenheng med empiriske data og/eller en større sammenheng. Eller: Minst to elever bruker fagbegreper som viser at de har begynnende forståelser for fenomenet det undervises i. De kan løse problemer i nye situasjoner ved å ta i bruk ervervet kunnskap.

Bruk av faglig språk

Kategorien fokuserer på hvordan læreren bruker naturfagbegreper i segmentet, om begrepene forklares og i hvilken grad elever oppfordres til å bruke relevante fagbegreper.

Undervisning gis høy kode dersom lærer gjennomgående bruker og forklarer fagbegreper, og elever får anledning til å bruke disse. Undervisning gis lav kode dersom fagspråk ikke blir brukt, eller ikke blir forklart.
Modifisert etter PLATO (Grossman et al., 2013).

Kode 1	Læreren verken introduserer, definerer eller ber elever bruke fagbegreper.
Kode 2	Læreren introduserer/definerer sjelden fagbegreper. Læreren og elevene bruker ikke fagbegreper i klasseromsdiskusjonen. Eller: Læreren bruker fagbegreper uten å forklare hva de betyr.
Kode 3	Læreren introduserer, fremkaller, inkluderer og understreker fagbegreper ofte.
Kode 4	Læreren introduserer, fremkaller, inkluderer og understreker fagbegreper regelmessig og gjennomgående i timen. Læreren gir elevene mange muligheter til å bruke begrepene.

Tilbakemelding

Kategorien fokuserer på kvaliteten på tilbakemeldinger som elever får når de bruker naturfaglige ferdigheter, begreper eller strategier. Tilbakemeldinger inkluderer både kommentarer på kvaliteten på elevarbeid og forslag til hvordan elever kan gjøre det bedre.

Tilbakemeldinger som kodes høyt, kjennetegnes ved å være spesifikke og rettet mot sentrale ferdigheter i en aktivitet. Tilbakemeldingene hjelper elever til å forstå kvaliteten på eget arbeid, og hjelper elever til å prestere siden de får bedre forståelse av hva en aktivitet går ut på. Tilbakemeldinger som kodes lavt kjennetegnes ved at de er vage og svakt knyttet til elevarbeid. Forslag til forbedringer er ofte prosessuelle, det vil si fokusert på instruksjoner for oppgaven i stedet for ferdigheter og kunnskap som elevene trenger. Disse kommentarene hjelper ikke elever til å måle egen fremgang eller blir flinkere til å løse oppgaven. Det kan også hende at svake tilbakemeldinger skaper forvirring eller misforståelser.

Tilbakemeldinger kan gis mens elever jobber med en oppgave eller etter at en oppgave har blitt fullført. Lærere kan også rette elevene mot en ny aktivitet ved å gi tilbakemelding på tidligere arbeid. For eksempel "Jeg la merke til at mange av dere var flinke til å bruke fagbegreper da dere snakket om magneter, så vi kommer til å bygge videre på det ved når vi skal skrive rapporten om magneter."

Ref.: PLATO (Grossman et al., 2013).

Kode 1	Læreren gir ikke tilbakemelding til elever.
Kode 2	Læreren eller elever gir tilbakemelding som er vage, repeterende eller misvisende (f.eks., "bra jobba," "riktig," "nei"). Forslag til hvordan elever kan bli flinkere fokuserer heller på prosedyrer enn fag. Lærerspørsmål som foreslår neste steg eller forbedringer, tilhører denne koden (f.eks. "Har du tenkt å legge til flere detaljer?").
Kode 3	Læreren eller elever gir tilbakemelding som er knyttet til spesifikke elevarbeider eller idéer. Tilbakemeldinger er konstruktive og tydelige. Forbedringsforslag er en blanding av prosessuelle og faglige.
Kode 4	Læreren eller elever gir regelmessig tilbakemelding som er knyttet til spesifikke elevarbeider eller idéer. Tilbakemeldinger er konstruktive og tydelige. Forbedringsforslag er hovedsakelig faglige. Læreren gir tilbakemelding som hjelper elevene til å oppklare misforståelser/hverdagsforestillinger.

4. Kognitiv aktivering

Denne dimensjonen består av tre kategorier: *kobling til tidligere kunnskap, intellektuell utfordring og elevrefleksjon.* Disse kategoriene fokuserer på i hvilken grad undervisningen utfordrer elevene kognitivt og fremmer refleksjon over forkunnskap og egen læring. Kategoriene retter seg mot lærerens aktivitet, og ikke hva elevene gjør.

Kobling til tidligere kunnskap	
Kategorien har fokus på i hvilken grad og hvordan læreren knytter elevenes tidligere fagkunnskap og personlige erfaringer til ny kunnskap i segmentet. Her er kunnskap og erfaringer både i og utenfor klasserommet inkludert. Forskning tyder på at det å knytte sammen ny kunnskap med det elevene tidligere har lært vil øke mulighetene for en dypere forståelse av fagstoffet, i tillegg til at elevene selv danner forbindelser mellom ny og tidligere kunnskap. **Koblinger til tidligere kunnskap som ikke settes tydelig i sammenheng med dagens undervisningsøkt, gis lav kode. Undervisning gis høy kode dersom læreren bygger på tidligere kunnskap for å videreutvikle kunnskaper og ferdigheter, i tråd med målet for timen.** **Ref.: PLATO (Grossman et al., 2013).**	
Kode 1	Verken lærer eller elever refererer til tidligere undervisning. Læreren fremkaller ikke elevenes forkunnskaper.
Kode 2	Læreren eller elevene kan referere kort eller overfladisk til tidligere undervisning, eller læreren forsøker å fremkalle elevenes forkunnskaper. Forbindelser mellom tidligere kunnskap og dagens undervisningsøkt er ikke tydelige.
Kode 3	Læreren fremkaller eller refererer til elevenes tidligere akademiske kunnskap eller personlige erfaringer flere ganger. Forbindelser mellom tidligere kunnskap og dagenes økt er tydelige nok til å kunne bidra til at elevene forstår det nye fagstoffet.
Kode 4	Læreren eller elevene refererer eksplisitt til tidligere undervisning og/eller fremkaller elevenes tidligere kunnskap (ett eller flere klare eksempler). Forbindelser mellom tidligere kunnskap og nye naturfaglige begreper eller oppgaver er tydelige, eksplisitte og spesifikt knyttet til det nye lærestoffet.

Intellektuell utfordring

Kategorien *intellektuell utfordring* fokuserer på i hvilken grad elevene utfordres kognitivt av aktivitetene de er engasjert i. Kognitivt utfordrende aktiviteter bidrar til at elevene tenker analytisk eller slutningsbasert. I motsetning krever mindre utfordrende aktiviteter bare at elevene pugger eller kan utenat. *Intellektuell utfordring* er også avhengig av i hvilken grad lærerspørsmål krever analytisk eller slutningsbasert tenkning.

I helklasseundervisning skal koding av *intellektuell utfordring* baseres på delen av arbeidet som er slutningsbasert eller analytisk. Når læreren underviser og spør grupper eller enkeltelever, bestemmes *intellektuell utfordring* ut fra aktivitetene slik de presenteres av læreren. Undervisningen justeres på bakgrunn av kommentarer og spørsmål fra elever og lærer.

Kognitivt utfordrende spørsmål kan opprettholde eller heve graden av intellektuell utfordring i undervisningen, og skal dermed kodes høyt for *intellektuell utfordring*. Motsatt vil spørsmål og kommentarer som fokuserer på å gjenkjenne og huske begreper, eller fokuserer på prosedyrer i ellers utfordrende oppgaver, bidra til lav kode for *intellektuell utfordring*.
Ref.: PLATO (Grossman et al., 2013).

Kode 1	Lærer legger til rette for aktiviteter eller oppgaver der elevene nesten bare trenger å pugge eller kunne utenat. Aktiviteter som å lese stille, høre på en forelesning eller se en film uten at elevene har fått oppgaver av analytisk eller reflekterende art, kodes på dette nivået.
Kode 2	Lærer legger til rette for aktiviteter eller oppgaver der elevene nesten bare trenger å pugge eller kunne utenat, men en liten del (10-50%) av segmentet oppfordrer til analyse, tolkning, trekke slutninger eller komme med ideer. Eksempel på at elevene må komme ideer: Lærer spør elevene hvorfor det er kaldt om vinteren og varmt om sommeren. Elevene foreslår at det er fordi vi er nærmere solen om sommeren. Læreren viser et bilde som illustrerer at dette ikke er tilfellet, og ber elevene om å diskutere og komme med ideer om hvorfor det er slik.
Kode 3	Lærer legger til rette for en blanding av aktiviteter eller oppgaver, som i størstedelen av segmentet (mer enn 50%) oppfordrer til analyse, tolkning, trekke slutninger eller komme med ideer, og som fokuserer lite på å pugge eller kunne utenat.
Kode 4	Lærer legger til rette for aktiviteter eller oppgaver som i stor grad fremmer sofistikert eller analytisk og slutningsbasert tenkning på høyt nivå, inkludert å komme med og vurdere ideer og informasjon og /eller begrunne svar og slutninger.

Elevrefleksjon

Denne kategorien fokuserer på i hvilken grad elevene oppfordres til å reflektere over hva de har lært og hva de har forstått om emnet.

Undervisning hvor læreren ikke ber elevene om å tenke over hva de har lært, eller gjengi hva timen har handlet om, gis lav kode. I undervisning med høy kode ber læreren eksplisitt elevene om å tenke over hvordan de har lært i løpet av timen, og fokus er på forståelse og å se sammenhenger mellom ny og eksisterende kunnskap.
Ref.: EQUIP (Marshall et al., 2009).

Kode 1	Lærer oppfordrer ikke eksplisitt elevene til å tenke over hva de har lært.
Kode 2	Læreren oppfordrer elevene eksplisitt til å fortelle/skrive ned hva denne økta har handlet om. Dette holdes på et nivå der elevene kun trenger å gjengi hva timen har handlet om
Kode 3	Læreren oppfordrer elevene eksplisitt til å forklare hva de har forstått av emnet de har jobbet med.
Kode 4	Læreren oppfordrer elevene eksplisitt til å fortelle/skrive ned hva de har forstått av emnet de har jobbet med, og kan knytte dette til tidligere kunnskap og/eller nye sammenhenger. Eller Læreren ber elevene eksplisitt om å tenke over hvordan de har lært i løpet av timen.

5. Klasseledelse

Denne dimensjonen består av to kategorier*: Atferd og tidsbruk*. Disse kategoriene beskriver hvordan læreren arbeider med organiseringen av klasserommet og hvordan undervisningstiden benyttes til naturfaglige aktiviteter.

Atferdshåndtering	
Denne kategorien fokuserer på i hvilken grad elevenes atferd er forenlig med hensikten for timen. Det ideelle klasserom er ikke nødvendigvis stille og kontrollert, det vil variere for ulike undervisningsformer. Det sentrale er om elevenes atferd er passende for oppgaven som er gitt. Et klasserom med god atferdshåndtering vil se annerledes ut i en time med oppgavejobbing enn i en time med utforskende arbeid i grupper. **I undervisning som kodes på høyt nivå for *atferd,* gjør elevene stort sett det de skal og responderer hurtig på beskjeder som «stille, vi må høre etter hva Ola sier». Gjentatte beskjeder om atferd kan være bevis for at elever ikke responderer.** **Ref.: PLATO (Grossman et al., 2013).**	
Kode 1	Klasserommet er uorganisert, og elevenes atferd er et stort hinder for læring. Det er mange tilfeller der forstyrrelser distraherer flertallet i klassen fra å lære. Ved eventuell reaksjon er konsekvensene ineffektive eller lærer følger dem ikke opp.
Kode 2	Klasserommet er delvis uorganisert, og elevenes atferd er av og til et hinder for læring. Det kan være enkelte tilfeller av forstyrrelser som distraherer flertallet i klassen fra å lære, eller mange avbrytelser for å bedre elevenes atferd. Ved eventuell reaksjon er konsekvensene ineffektive eller lærer følger dem ikke opp.
Kode 3	Klasserommet er for det meste godt organisert. Elevenes atferd fremmer læring. Det kan være enkelte forstyrrelser som kan hindre læring for enkelte eller noen få elever, men ingen forstyrrelser som hindrer læring for flertallet. Ved eventuell reaksjon er konsekvensene klare og konsistente.
Kode 4	Klasserommet er velorganisert, elevens atferd fremmer læring. Det er ingen eller nesten ingen forstyrrelser eller avbrytelser som hindrer læring, og elevene kan i noen tilfeller justere egen og andres atferd. Ved eventuell reaksjon er konsekvensene klare og konsistente.

Tidsbruk	
Denne kategorien fokuserer på hvor mye av tiden elevene er engasjert i naturfagrelaterte aktiviteter. Det er fokus på om lærer organiserer klassen effektivt slik at mest mulig av tiden brukes på fagrelaterte ting. Tidsperioder med utenomfaglige aktiviteter kan forekomme på grunn av manglende prosedyrer og rutiner. I tillegg kan problemer med atferdshåndtering påvirke tidsbruk. For eksempel vil en lærer som bruker mye av hele klassens tid for å irettesette elevers oppførsel, kodes lavt på *tidsbruk*. **Ref.: PLATO (Grossman et al., 2013).**	
Kode 1	Lærer gir ikke aktiviteter til elevene. Det er lange perioder (omtrent 5 minutter eller mer) med dødtid eller forvirring. Lite eller ingenting oppnås. Eventuelle overganger mellom aktiviteter tar mye tid og er veldig uorganisert.
Kode 2	Selv om lærer gir aktiviteter til elevene, er det lange perioder med dødtid (omtrent 2 til 5 minutter). Det brukes vesentlig mindre tid på aktivitetene enn planlagt. Eventuelle overganger mellom aktiviteter tar tid og er noe uorganisert
Kode 3	Lærer gir aktiviteter, men det er noen korte perioder (omtrent 1 til 2 minutter) dødtid. Eventuelle overganger mellom aktiviteter flyter greit selv om det er noe ineffektivt.
Kode 4	Undervisningen har god flyt, og det er mindre enn 1 minutt med dødtid. Lærer observerer elevene og justerer tiden på oppgaver deretter. Eventuelle overganger mellom aktiviteter flyter greit og effektivt og krever lite tilrettelegging fra lærer.

Registreringer fra klasserommet

Registreringer fra klasserommet	
Helklasseundervisning	Det forekommer at elevene er samlet for felles undervisning
Gruppearbeid	Det forekommer at elevene arbeider i grupper
Individuelt arbeid	Det forekommer at elevene arbeider enkeltvis
Dominerende klasseromsorganisering	Dominerende arbeidsform: helklasseundervisning, gruppearbeid eller individuelt arbeid
Praktisk arbeid	Det forekommer at elevene arbeider med en praktisk aktivitet, som for eksempel forsøk eller prosjekter. Omfatter ikke arbeid med animasjoner og simuleringer eller tekstrelatert arbeid.

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Appended papers

Paper 1: Instructional quality

Sæleset, J., Olufsen, M., & Karlsen, S. (Under review). Quality of beginner pre-service teachers' science instruction. *Acta Didactica Norden.*

Quality of beginner pre-service teachers’ science instruction

Abstract

Teachers’ instructional quality is important for students’ learning outcomes, but research on beginner middle school pre-service teachers’ (PSTs’) instructional quality and development is limited. In this case study, we investigated the quality of beginner PSTs’ science instruction. All the science lessons of six PSTs (N = 21) during the school practica in their first year in a teacher education program were video-recorded. Video data were analyzed using categories from the Linking Instruction in Science and Student Impact observation manual. Our analysis focused on crucial aspects of quality science instruction: cognitive activation, discourse features, instructional clarity, and scientific inquiry. Studied as one case, the six PSTs showed surprisingly high scores for categories related to student-centered teaching and implemented practical activities with connections to science concept learning. However, the PSTs only challenged students intellectually to a moderate degree and rarely performed inquiry teaching. Additionally, their representation of science content varied greatly in quality. Results are discussed and implications for teacher education are outlined.

Keywords: Instructional quality, pre-service teachers, teacher education, science education

Sammendrag

Læreres undervisningskvalitet er viktig for elevers læringsutbytte, men det finnes lite forsking på lærerstudenters undervisning tidlig i utdanningsløpet og utvikling av denne. I denne kasusstudien undersøkte vi kvaliteten på lærerstudenters naturfagundervisning tidlig i utdanningen. Vi filmet alle naturfagtimene (N=21) til seks lærerstudenter som var i praksis i deres første studieår. Videodata ble analysert med kategorier fra LISSI-prosjektets (Linking Instruction in Science and Student Impact) observasjonsmanual. Analysene fokuserte på undervisningskvalitet i naturfag: kognitiv aktivering, tilrettelegging for diskusjon, tydelig undervisning og naturfaglig utforskning. Sett som ett kasus viste de seks lærerstudentene overraskende høye skår for kategorier relatert til elevsentrert undervisning, og gjennomførte praktiske aktiviteter som var koblet til læring av naturfagbegreper. Lærerstudentene utfordret likevel elevene bare i middels grad og gjennomførte sjelden utforskende undervisning. Det var også stor variasjon i kvaliteten på representasjoner av fagstoff. I artikkelen er resultatene diskutert, og vi drar slutninger for lærerutdanning.

Stikkord: Undervisningskvalitet, lærerstudenter, lærerutdanning, naturfag

Introduction

Earlier research has suggested that teachers' instructional practices are of importance for school student outcomes, even more than factors like class size, classroom climate, and teachers' years of experience and formal training (Hattie, 2009; Klette et al., 2017). In their review of research on teacher effectiveness, Seidel and Shavelson (2007) suggested that among different variables related to teaching, student outcomes were most affected by execution of learning activities, particularly in science. Pre-service teachers (PSTs) spend significant amounts of time on teaching activities in school practica (Cohen et al., 2013), which represents opportunities to develop their teaching practices within initial teacher education. However, it is notable that a solid research base on PSTs' early teaching practices has yet to be developed. This is partly due to a low number of studies available, and partly due to their reliance on low-quality measures and interpretations based on self-reports (Lawson et al., 2015; Wilson et al., 2001). Specifically, the field lacks video studies of actual classroom teaching (Ratinen et al., 2015). In the current paper, we thus make a needed contribution as we report PSTs' instructional practices using video recordings and an evidence-based observation manual.

Literature review: Pre-service teachers' instructional practices

In this section, we review research on pre-service teachers' (PST) instructional quality. We use the term pre-service teacher for a person undergoing teacher education, while student refers to a kid in compulsory school. Studies of science instruction in school practica are limited in number (Cohen et al., 2013; Lawson et al., 2015). In one of them, Baeten et al. (2013) found that PSTs seldom delivered student-centered teaching. That is teaching where students are active participants in their learning rather than passive recipients of information. Further, studies have found PSTs to focus on themselves when they teach (Juhler, 2017; Kagan, 1992; Körkkö et al., 2016). A common concern among PSTs is classroom management, which leads them to design activities that give them more control (Zembal-Saul et al., 2002). When PSTs assume the role of a transmitter of information, it limits their ability to consider students and their learning (Brown et al., 2013; Geddis & Roberts, 1998). In a small case study, Mellado (1998) found that PSTs were incapable of transferring much of their knowledge about science teaching into the classroom. None were able to systematically address individual students’ ideas or monitor their learning individually. Similarly, a study of 20 Finnish PSTs by Ratinen et al. (2015) showed that participants lacked ability to foster student thinking. The participating PSTs ignored students’ prior knowledge, although they had planned to teach dialogically (Ratinen et al., 2015). In another study, Kang (2017) investigated eight PSTs’ lesson planning and enactment. Using plans for and reports from instruction, records of teaching, and curricular materials, she found only three of the PSTs to increasingly or consistently use cognitively challenging tasks, as they were trained to do. The other five PSTs were too focused on content or process, leading them to use low-demand tasks.

In one contrasting study Thompson et al. (2013) identified PSTs’ ability to carry out quality teaching including adapting instruction to build on student ideas. They studied teachers during university coursework in their initial teacher education, in school practica, and in their first year in service. Using classroom observations and teacher interviews, they found that eleven of the 26 participating PSTs successfully integrated teaching practices such as adapting instruction to build on students’ ideas. The ideas underlying these practices were appropriated during methods courses or school practica during initial teacher education and enacted early in practicum.

Theoretical framework: Instructional quality

Inspired by Shulman (1986), we see quality teaching as not just acting, but enacting a knowledge base. Pedagogical content knowledge (PCK), introduced by Shulman (1986) has been found a useful framework for science teacher knowledge (Chan & Hume, 2019). Teachers with elaborated PCK provide students with quality instruction (Fauth et al., 2019), particularly reform-oriented teaching (Park et al., 2011). In reform-oriented teaching, teachers consider students and content rather than delivery of content only, and they implement inquiry teaching (Anderson et al., 1994; Sawada et al., 2002). Reform-oriented teaching align with constructivist learning theories, by its focus on the students as active learners rather than the teacher as supplier of information (Anderson et al., 1994).

Thus, we view enactment of elaborated PCK, particularly in the form of student-centered and inquiry-based teaching as quality instruction. We use three central dimensions of instructional quality from a framework proposed by Klette et al. (2017): cognitive activation, discourse features, and instructional clarity. Further, we include scientific inquiry, representing a particularly important dimension of the subject of science (Crawford, 2014). Together, the four dimensions of instructional quality presented below cover instructional quality in connection with PCK.

Cognitive activation

The dimension of cognitive activation concerns whether students are engaged in higher-level thinking such as reflection, analysis, and comparison of ideas (Klette et al., 2017). In less cognitive-activating instruction, students are provided with tasks that merely require them to repeat and recall information (Lipowsky et al., 2009). Cognitive activation also increases when students' prior knowledge is activated (Grossman et al., 2013), and they are explicitly asked to reflect on their own learning (Lipowsky et al., 2009). Research have found cognitive-activating instruction to rise student achievement (Fauth et al., 2019; Neumann et al., 2012), and moderate challenging instruction to motivate students (Turner & Meyer, 2004).

Teachers with well-developed PCK are better able to give cognitively activating instruction (Fauth et al., 2019). They use knowledge of students' misconceptions and difficulties with the science content to provide intellectual challenging questions (Förtsch et al., 2016).

Discourse features

The dimension of discourse features captures discussion formats as well as the quality of responses provided to students. In science it is important to allow students to argue and justify their ideas. Through this, dialogic classroom discourse eventually increases students' science competency (Neumann et al., 2012; Scott et al., 2006; Treagust & Tsui, 2014). At lower levels, discourse might follow the initiation–response–evaluation format, with the teacher closing the discussion without prompting further student responses (Scott et al., 2006). At higher levels, discourse is dialogic in format, with the teacher offering prompts for further elaboration and extending dialogues between the teacher and students or between students (Scott et al., 2006).

The relationship between PCK and dialogic discourse is similar to that with cognitive activation. To engage students in discussions about science ideas, teachers need to know these ideas (knowledge of students' understanding of science, a PCK component) as well as approaches to initiate meaningful discussions (knowledge of instructional strategies, a PCK component).

Instructional clarity

This dimension includes the clarity and explicitness of the learning goals, presented content, and feedback on students' work and ideas. It relies upon representations, explanations, and precise use of scientific language (Klette et al., 2017). Understood as interactions between teachers and students rather than transmissive teaching, explanations are a core element of teaching (Kulgemeyer et al., 2020). Research has documented the usefulness of instructional representations in science teaching to improve students' cognitive and affective outcomes (Treagust & Tsui, 2014; Tytler et al., 2013). Constructive feedback is an important aspect of supporting students' construction of knowledge, sensemaking, and conceptual change (Fauth et al., 2019; Grossman et al., 2013).

Finally, instructional clarity in science emphasizes the need for real-life experience with science phenomena, as in practical activities. Students engaged in practical activities are known to have increased potential for learning science, especially if the practical activities involve working in groups and focus on developing scientific ideas (Abrahams & Millar, 2008; Hofstein & Kind, 2012).

Knowledge of what makes the content difficult, knowledge of specific misconceptions, and knowledge of instructional strategies with explanatory power are central elements in PCK (van Driel et al., 2014). Thus, instructional clarity is closely connected to PCK.

Scientific inquiry

The scientific inquiry dimension concerns the appearance and quality of inquiry teaching where teachers engage students in investigations. It is related to scientific reasoning, a feature of quality instruction which focuses on inductive and deductive reasoning (Treagust & Tsui, 2014). Postman and Weingartner (1969) made the case that students need to develop the art and science of inquiring rather than remembering explanations from a teacher or a book.

Three important phases have been emphasized by researchers of scientific inquiry: ask a question and plan an investigation, carry out the investigation and organize data, and reason based on the findings to draw conclusions (Bybee et al., 2006; Knain & Kolstø, 2019). Through scientific inquiry, students can achieve cognitive gains and increased interest in science (Crawford, 2014). Also, they can develop competence related to the nature of scientific knowledge (Lederman & Lederman, 2019).

Central components of PCK has been found to correlate with reform-oriented inquiry teaching (Park et al., 2011). Teachers’ knowledge of students’ understanding of science (a PCK component) may facilitate teachers’ use of inquiry (Suh & Park, 2017).

Aims and research question

We address the need for studies on school practica science teaching with a video study based on complete sets of six beginner PSTs’ science instruction in two three-week school practica in grade 6 and 7. Using a standardized video observation manual, we analyze beginner PSTs’ instructional quality in the subject of science, which were one of three teaching subjects selected by the PSTs themselves. The following research question guided the study: “What is the quality of six beginner pre-service middle school teachers’ science instruction in school practica?”

Methods

This is a qualitative case study of six pre-service teachers’ science teaching. We treated the six PSTs as one case and investigated it in the context of school practica in initial teacher education. The case study approach acknowledges the close connection between the phenomenon and the context (Yin, 2014). We studied PSTs’ instructional practices in science, connected to the context of the school practicum.

Context

Teacher education programs in Norway were recently extended from four-year undergraduate programs to five-year Master of Education programs. The PSTs participating in the current study aimed to teach grade 5–10 students. At the time of data collection, they were enrolled in courses on pedagogy and student knowledge, research and development in education, and specialized content courses for teachers in two subjects of their choice. All six PSTs chose science as their main subject. First-year specialized science courses intertwined content knowledge and pedagogy in the following topics: basic geology, chemistry, and physics, biology in the intertidal zone, sexual health, waves and sound, the solar system, and technology and design. Other courses included students' learning, classroom leadership, additional teaching methods, educational research, and the nature of science. All PSTs' courses maintained a focus on students and student learning. For example, in their pedagogy and student knowledge course, PSTs discussed the Piagetian theory of learning in connection to lesson design, and the specialized science courses used student-centered instructional strategies. The first author was a specialized science course instructor before and between the school practica. To avoid conflicts of interest with the research study, the first author did not participate in formal assessment of the PSTs in these two units. The first year of the program also included two school practica, one in the fall semester and one in the spring semester. These involved approximately three weeks of mentored teaching activities and group discussion about the teaching.

Participants

At the start of their first semester in the first year, all PSTs in one teacher education program cohort with science as their main subject were invited to participate in the study. At the same time, two experienced schoolteachers from two different schools were recruited as mentor teachers among those engaged to mentor PSTs in the cohort. PSTs worked in groups of three, which were organized by the program administration, during the school practica. The program administrators assigned the groups mentor teachers and schools. Two full groups were available for this study. These were the only ones consisting exclusively of PSTs that gave consent to participate in the study, and whose choice of second and third school subject somehow matched with the two selected mentor teachers' expertise. Thus, the six PSTs in these groups, aged 19-24 years, were chosen as participants in the study. Three of them had no science specialization from high school, while the other three had two years or more of biology, chemistry, and/or geology courses. Likewise, the participants' teaching-related experience varied greatly. One participant had no such experience, three had experience leading leisure activities for kids, and two had experience from classrooms. The PSTs' exam results in specialized science courses in the first year of the program ranged from A to F, with C as the average, similar to the rest of the cohort.

Three PSTs' practica took place in a grade 7 classroom with 32 students. These were two females and one male. Their female mentor teacher had more than 10 years of experience. Although she was not a certified science teacher, she enjoyed teaching science. The other three PSTs, also two females and one male, were placed in another school in a grade 6 classroom with 20 students. Their male mentor teacher had more than 10 years of experience and was a certified science teacher.

Data collection

In total, the participating PSTs taught 21 science lessons during the two cycles of three-week school practica. All lessons were recorded. Two small wide-angle cameras captured the classroom teaching, and the PSTs carried a microphone. The primary camera overviewed the classroom, facing the PST. The secondary camera captured the same events but faced the students. In addition to video data, reflections and observations of the context were gathered in an unstructured log.

We benefited from rich and less selective observations made possible with video recordings compared to direct observation (Erickson, 2006). The use of two cameras strengthened the reliability of analyses, as events of interest could be viewed from two angles. The first and second author analyzed the material together, increasing inter-rater reliability (Blikstad-Balas, 2017).

Video recording in classrooms raise ethical issues. First, the presence of cameras and a researcher obviously affected the social settings of the classrooms. To handle this issue, the PSTs were asked to give advice regarding when video recordings would be suitable. As in earlier classroom studies (Blikstad-Balas, 2017), students seemed to forget the video cameras were there and became used to the presence of the researcher. In two lessons on sexual health, we collected only audio recordings without the researcher present, as advised by the PST. Prior to the recordings, we retrieved written and informed consent from all participating PSTs, the mentor teachers, and the students' parents.

Data analysis

We analyzed the data using categories from the Linking Instruction in Science and Student Impact (LISSI) video observation manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020). The LISSI manual was based on the Protocol for Language Arts Teaching Observation (PLATO; Grossman et al., 2013) and inspired by the Electronic Quality of Inquiry Protocol (EQUIP; Marshall et al., 2010) and the video manual used in the Budding Science and Literacy project (Ødegaard et al., 2014). The LISSI manual was refined through several rounds of review of research and analysis of classroom teaching, ensuring valid measure of critical dimensions of science teaching practice. Inter-rater reliability was found to be satisfactory (Ødegaard, Kjærnsli, Karlsen, Kersting, et al., 2020). Twelve out of the 19 categories in the LISSI manual were used in our analysis due to their relevance to our theoretical framework (Table 1). In the coding procedure, the science lessons were divided into 15-minute segments (N = 71). Each segment was scored from 1–4 based on the evidence in the video and criteria in the manual. A score of 1 indicated almost no evidence of the targeted practice, 2 indicated limited evidence, 3 indicated evidence with some weaknesses, and 4 indicated consistent strong evidence. Clear descriptions of observable characteristics for each score contributed to trustworthy analysis of instruction. Topics varied across lessons. In the results, we include descriptions of the teachings, to ensure transparency around this issue.

Table 1

Categories in video coding guide with descriptions of evidence indicating low-end and high-end scores

Evidence for low-end scores (1–2)	Evidence for high-end scores (3–4)
Cognitive activation: Activation of student thinking.	
Connections to Prior Knowledge[1]	
If students' prior knowledge or experiences are referred to, it is done briefly or superficially and is not sufficiently connected to the day's lesson.	Students' prior knowledge or experiences are elicited or referred to multiple times and are connected to the day's lesson.
Intellectual Challenge [1]	
Students spend most of their time on activities or assignments that are rote or recall.	Students spend most of their time on activities or assignments with high academic rigor that promote analysis, interpretation, inferencing, idea generation, or high-level analytical and inferential thinking.
Student Reflection [2]	
If students are encouraged to reflect on their learning, it is only at the level of remembering what the lesson was about.	Students are encouraged to reflect on their understanding of the lesson or to think at higher levels.
Discourse features: Facilitation of science discourse.	
Teacher Role [2]	
The teacher is the center of the lesson or only occasionally facilitates student–student talk.	Rather than being the center of the lesson, the teacher facilitates student–student talk.
Classroom Discourse [1]	
a) Opportunities for student talk: If they arise, opportunities for science-related discussions are short or characterized by recitation. b) Uptake of student responses: Responses by the teacher and students responses usually do not elaborate on or help develop students' ideas.	a) Opportunities for student talk: Open-ended science-related questions are discussed at some length. b) Uptake of student responses: The teacher and students carefully listen to each other and elaborate on or help develop science ideas.
Instructional clarity: Strategies for teaching new content.	
Representation of Content [1]	
If provided, the teacher's explanations, examples, illustrations, models, and analogies are incomplete, perfunctory, weak, or incorrect.	The teacher presents accurate and clear explanations, examples, illustrations, models, or analogies. Nuances of concepts and student misunderstandings may be addressed.
Use of Academic Language [1]	

Evidence for low-end scores (1–2)	Evidence for high-end scores (3–4)
The teacher rarely or never uses any scientific language, or it is used but not explained.	The teacher uses and explains scientific language, and students have opportunities to use it.
Feedback [1]	
If the teacher or students provide feedback on students' work or ideas, it is mainly vague, repetitive, perfunctory, or misleading. Suggestions for how to improve performance are procedural rather than substantive.	The teacher or students provide constructive feedback that specifically addresses students' work or ideas.
Practical Activities [4]	
If students interact with objects beyond materials for reading or writing, these practical activities are not tied to learning science concepts.	Students interact with objects beyond materials for reading or writing. Practical activities are connected to learning science concepts.
Scientific Inquiry: Phases of inquiry teaching.	
Preparation for inquiry [3,4]	
No researchable questions, hypotheses, or predictions are developed. However, the teacher may activate students' prior knowledge or invite them to wonder about science.	A researchable question, hypothesis, or prediction is developed. Further inquiry may be planned by the teacher or students.
Data Collection [3,4]	
Students may perform observations or investigations with or without addressing a researchable question, hypothesis, or prediction. Data are not documented.	Students perform investigations to address a researchable question, hypothesis, or prediction. Data are documented and may be systemized.
Consolidation [3,4]	
Students may discuss observations or data. However, while they may draw simple descriptions from them, no conclusions are made.	Students draw conclusions from observations or data. They may connect these to scientific theoretical knowledge and discuss the implications.

Note. The selected categories from the LISSI manual. Literature bases for the categories: [1] Grossman et al. (2013). [2] Marshall et al. (2010). [3] Ødegaard et. al. (2014). [4] A new category in the LISSI manual (Ødegaard, Kjærnsli, Karlsen, Lunde, et al., 2020).

The authors were certified as reliable raters of the PLATO categories. To ensure the manual was valid, the categories were discussed and found to correspond with observed classroom practices. The first and second author co-coded 20% of the material. In three cycles, the first and second author coded identical segments, discussed and revised any differing scores, and clarified the video observation manual to ensure reliable analysis of science teaching practices. Of the 14 segments coded in this process, 90.5% of them were scored identical or within 1 score point by both raters. The first author coded all 71 segments based on the clarified observation manual.

The results were more characterized by similarities among PSTs than by the detected differences. We calculated variance on the PSTs' average scores. Across all categories, the average variance was 0,16. This supported a focus on the PSTs as one case rather than separate cases. To look for patterns in frequencies of high- and low-end as well as average segment scores for each of the 12 video coding categories, we grouped the segments based on school practicum 1 or 2, lesson, location of segment within lesson, and depth of the lesson. In-depth lessons were characterized by explicit learning goals related to conceptually difficult concepts (defined as abstract and dynamic; Chi, 2000), and a sustained attention to these concepts during the instruction.

Results

Scoring results are showed in supplemental Table S1. The six participating PSTs each taught 3–4 science lessons during the two school practica. Some topics were covered in a single lesson, others were taught over several lessons. Each lesson included two to nine 15-minute segments, with a total of 71 segments. Table 2 provides an overview of the recorded lessons, including their topic, depth, and duration.

Table 2

Overview of recorded lessons

Lesson	Topic	In-depth lesson	Duration in 15-minute segments
1	Nutrients	Yes	2
2	Sexual health	No	2
3	Sexual health	No	4
4	The eye	No	2
5	The eye	No	4
6	Animals, nutrition	No	3

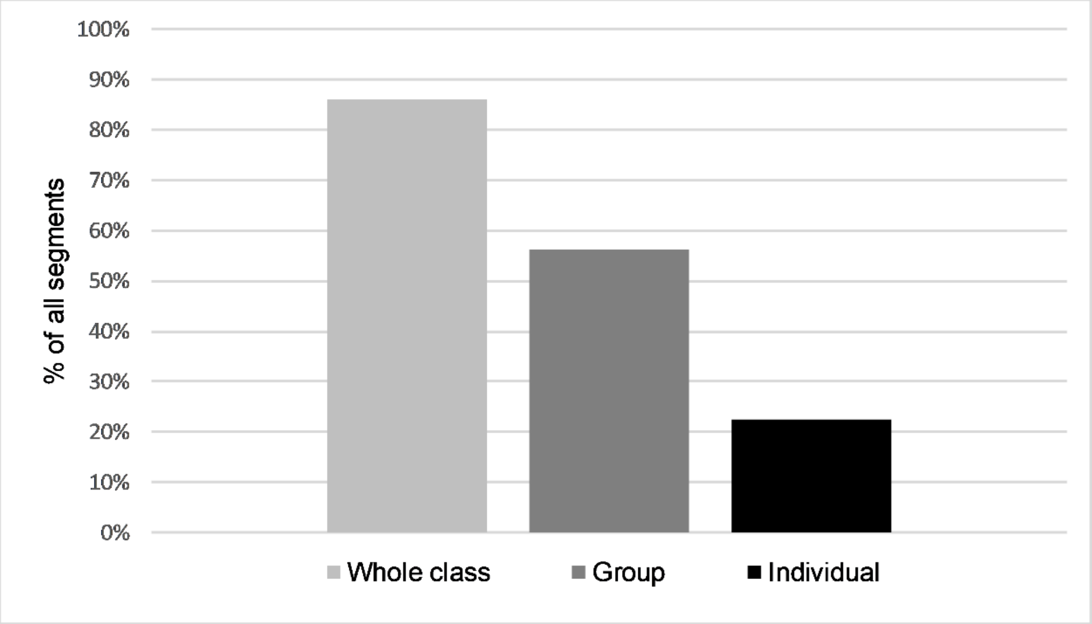
Lesson	Topic	In-depth lesson	Duration in 15-minute segments
7	Drugs	No	5
8	Energy content in food	Yes	2
9	Sexual health	No	2
10	Sexual health	No	4
11	Male puberty	No	3
12	Energy	Yes	3
13	Energy and fuel	Yes	4
14	Energy sources	Yes	3
15	Female puberty	No	2
16	Renewable energy	Yes	4
17	Fossil fuels	Yes	5
18	Puberty	No	3
19	Energy	Yes	2
20	Technology and design	Yes	9
21	Technology and design	Yes	3
TOTAL			71

Note. Six different PSTs taught the lessons. The last segment in a lesson varied from 6–20 minutes.

The class organization (whole-class, group, and/or individual) was recorded for each 15-minute segment. Figure 1 shows class organization across all segments.

Figure 1

Class organization across segments



Note. Organization of class codes in all segments for all six PSTs (N = 71). Segments with more than one class organization could be assigned multiple codes.

In a typical segment, the PSTs shifted between whole-class and group work. Both these categories were assigned to more than half the segments. Occasionally, students worked individually.

Instructional quality

We analyzed instructional quality of all segments. We present results for all PSTs together to reveal main findings related to the four dimensions of instructional quality. Scores are given from 1 (low) to 4 (high).

PSTs activated students’ prior knowledge, but intellectually challenged students to only a moderate degree

We identified multiple high-end scores (3-4) for the category *connections to prior knowledge* (39% of the segments; Fig. 2). These scores were spread across 90% of the lessons, indicating that PSTs usually referred to students’ prior knowledge and experiences, and connected it to the current lesson. In the following example from lesson 16, the PST connected students’ prior knowledge and experiences to the topic of renewable energy. First, students were asked to share their prior knowledge. Then, the PST connected their experiences and knowledge to the instruction:

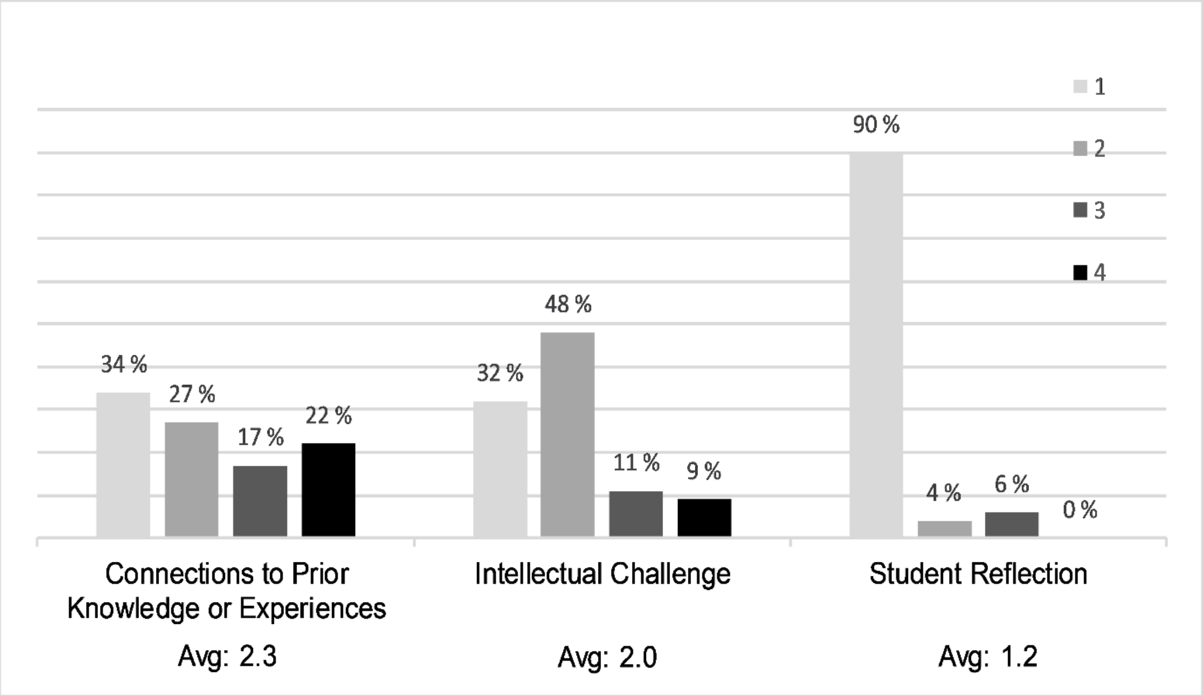
> Student: ‘In Turkey, when I was there two times ago, there was only one windmill. But when we returned this summer, there were like 10 windmills.’ PST: ‘More and more windmills are built, is that what you try to say? Yes! That is the intention in Norway too, as you might read about in the textbook.’

In this segment, the PST connected a student’s holiday experience with the situation in Norway, before this experience was later explicitly connected to the function of windmills. The segment was therefore scored 4 in the *connections to prior knowledge* category.

Results on *intellectual challenge* and *student reflection* (Fig. 2) indicate that PSTs struggled to make the instruction intellectually challenging, and prompt students to reflect upon their learning. In just 10% of the segments, PSTs initiated student reflection. The category *intellectual challenge* measures whether PSTs provided activities, assignments, and questions with high academic rigor. In one-third of the segments, more than 90% of the time was dominated by rote or recall activities, resulting in a score of 1 (Fig. 2). In half of the segments, PSTs promoted analysis, interpretation, inferences, or idea generation 10–50% of the time, resulting in a score of 2. This was the case for a segment on nutrition from lesson 6. The PST challenged students to analyze their prior knowledge and infer the role of proteins in a diet. However, students answered superficially, and for the rest of the segment, they were asked to match cards with explanations given earlier in the lesson. Therefore, this segment received a score of 2 for *intellectual challenge*.

Figure 2

Cognitive activation, activation of student thinking



Note. The coding for categories within the dimension cognitive activation across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of the score across all segments. Avg: average score across all segments.

Scores for *intellectual challenge* increased from the first to the second school practicum, when there were also more in-depth lessons. High-end scores were awarded to 6% of the first practicum segments but 25% of the second practicum segments (Table 3). The increase in scores for *intellectual challenge* was evident for all six PSTs.

Table 3

Scores for the category intellectual challenge per school practicum

School practicum	Number of segments	High-end scores	Low-end scores
1	18	6%	94%
2	53	25%	75%

Segments with high-end scores for *intellectual challenge* were never in the start of lessons.

Discourse in the classrooms was dialogic, and PSTs facilitated student-student talk

PSTs frequently facilitated activities or discussions that required students to take an active role. They picked up on students' contributions, and, to varying degrees, kept individual students' contributions in focus during their lessons. This was indicated by high scores for *teacher role* and *classroom discourse.* Their instruction was not dominated by the transmission of science content to a group of passive receivers.

In regard to *teacher role* (Fig. 3), 34% of the segments achieved high-end scores, as the PST did not orient the lesson around herself as center of the lesson. These segments were dominated by student-student talk and cooperative solving of tasks. Student–student talk was facilitated in both group work and whole-class settings. As an example, in lesson 17 on fossil fuels, students were talking together most of the second segment as they cooperated in making a poster with as many oil-based products as possible. This segment was therefore scored 4 on *teacher role.* Also, 27% of the segments were scored 2, making a total of more than half the segments characterized with presence of students' internal discussions or solving problems.

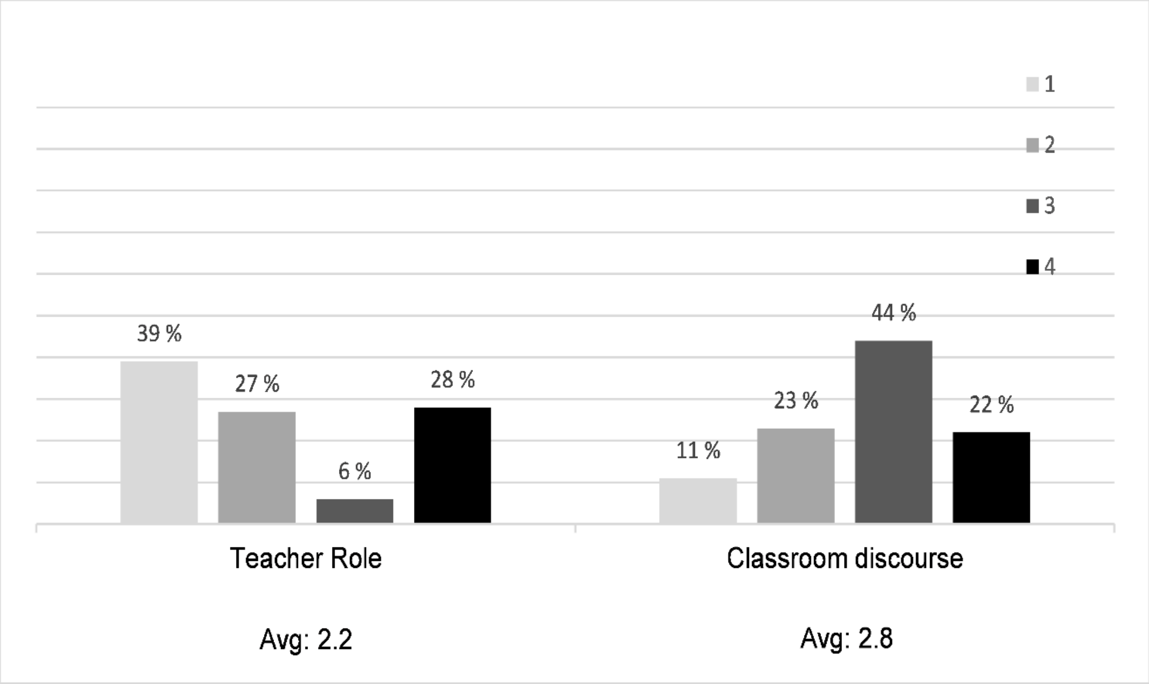
To achieve a high-end score for *classroom discourse*, communication patterns should involve students and teacher carefully listening to each other, and the teacher should tailor the dialogue to fit students' emerging understanding. In total, 66% of the segments achieved high-end scores (Fig. 3), including the conversation about windmills cited above. In this segment, the PST built upon a student's contribution in the form of the experience from Turkey, making the student an important contributor to the lesson. However, the discourse in this segment was mainly directed by the PST, which resulted in a score of 3. A score of 4 was reached in 23% of the segments (Fig. 3), including a segment from lesson 14 focusing on energy sources. In the segment, students were asked to discuss whether a system with a light bulb connected to a solar panel would work inside a dark room. This conversation took place in the whole-class part of the discussion:

> Student 1: 'We believe the solar panel is able to get the bulb to light up.' PST: 'So it will work?' Student 2: 'Not eternally, because the solar panel needs sunlight to produce electricity.' Student 3: 'Or strong enough light.' PST: 'But we found out that it works. This bulb is strong enough [to make the solar panel produce electricity].'

In this conversation, multiple students discussed an open question while the teacher acted as a facilitator. Contributions from students were picked up by the PST, which furthered the conversation. The PST guided the conversation towards energy loss to heat, and then the group concluded that the system would not work.

Figure 3

Discourse features, facilitation of science discourse



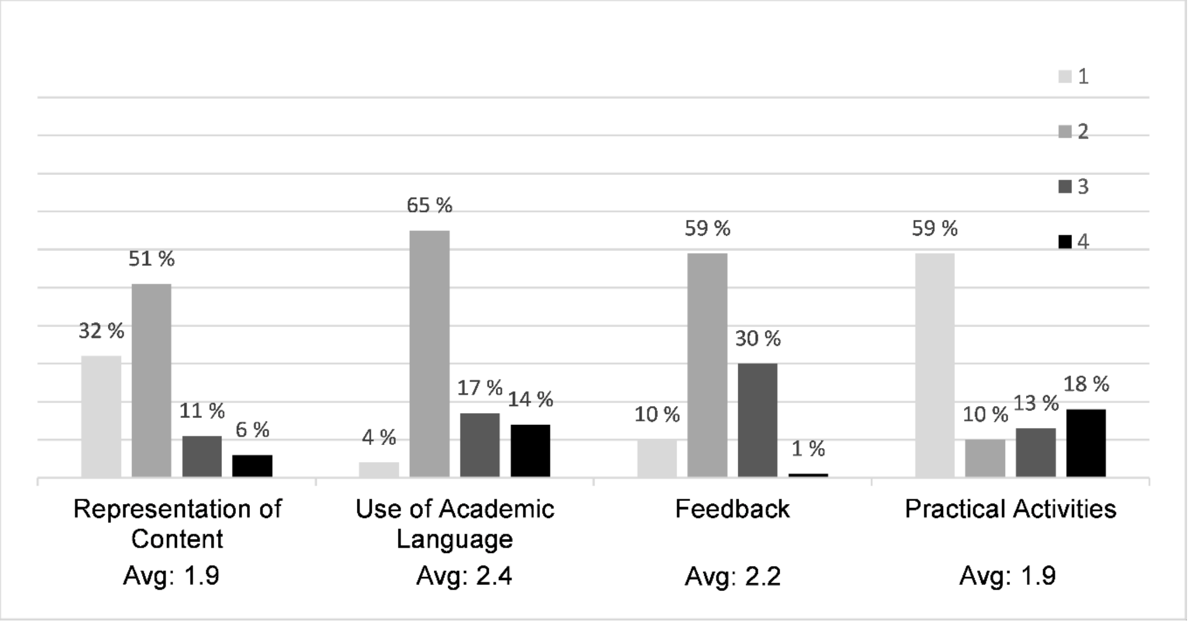
Note. The coding for categories within the dimension discourse features across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of the score across all segments. Avg: average score across all segments.

PSTs sometimes struggled to present science content with clarity, but they effectively used practical activities

Illustrations, examples, models, analogies, and explanations were often absent, incomplete, or perfunctory in the lessons. When the PSTs used academic terms, they seldom explained them. This resulted in low scores for *representation of content* and *use of academic language*. High-end scores for *representation of content* were awarded to just 17% of the segments. In order to score at high-end for *use of academic language,* PSTs had to use and explain academic terms. One example of high-level use of academic language was found in lesson 1 on nutrients, where the PST explained and used the concept of proteins and prompted students to use and explain this and other concepts in a card-sorting group activity. Such use and explanation of academic language characterized just 31% of the segments (Fig. 4). In many lessons, PSTs provided hardly any accurate and clear representations, and academic terms were either not used or not explained. Rather than taking opportunities to clarify students' misconceptions, those were sometimes reinforced. In lesson 20, which focused on technology and design, the PST erroneously guided students to think that the direction of a DC current is important for lighting an incandescent bulb; when a student asked, 'Which way should the battery be?' the PST replied, 'Good question, we will sort that out [...]. The longest [points at battery terminal] is minus, so it should be this way.' Later, the PST repeated this incorrect guidance to another group: 'Turn it [the battery] the other way. This is plus and this is minus. You need to keep an eye on that' (Lesson 20). This segment included no *use of academic language* (score 1), and *representation of content* was scored 1 due to the incorrect communication about light bulbs and current in the conversations above.

Figure 4

Instructional clarity, communication of science content knowledge

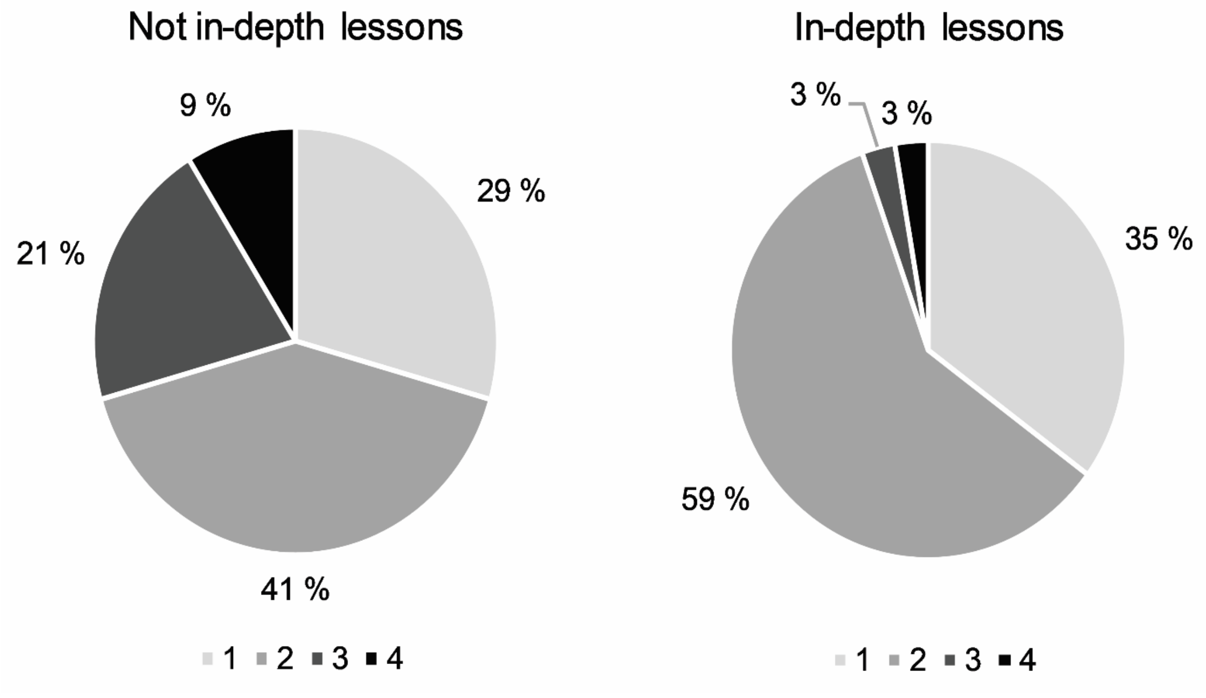


Note. The coding for categories within the dimension instructional clarity across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of the score across all segments. Avg: average score across all segments.

The quality of representations depended on the depth of the lesson. Incomplete and perfunctory representations were more frequent in in-depth lessons (Fig. 5). In lessons that did not go into depth, the PSTs provided more accurate and clear representations. One example of this was in lesson 15 where the PST taught about female puberty without going into depth on abstract or dynamic features of puberty, or even teaching about the central hormone estrogen. However, the representations she did use were often accurate and clear. In the second segment, scored 4 for *representation of content,* she explained the menstruation cycle with nuances regarding the duration of a cycle. She addressed a misconception about menstrual blood being different than other blood by viewing an effectful TV commercial for sanitary pads.

Figure 5

Scores for representation of content in lessons classified as in-depth and not in-depth



Note. The coding represents all PSTs' instruction across all segments (N = 71).

Further, we also noted for *representation of content* that high-end scores indicating accurate and clear representations typically took place when students were organized in whole-class instruction, and the PST was at the center of the lesson (low-end scores for *teacher role*). The above example from lesson 15 also illustrates this. The accurate and clear representations about female puberty were provided while the PST was leading the classroom conversation (low score for *teacher role*). In other words, PSTs were able to provide more accurate and clear representations during planned presentations. When they had to engage in unplanned interactions, their instruction sometimes indicated they had limited CK, and scored lower on *representation of content*.

The category *feedback* focuses on the quality of feedback provided in response to students' application of science skills, concepts, or strategies. To achieve a high-end score for *feedback*, PSTs or students should provide specific feedback on students' work or ideas that challenged them to further develop their thinking. In total, 59% of the segments scored 2 in this category (Fig. 4), indicating that the feedback provided to students was vague (e.g., "good job," "right," "no").

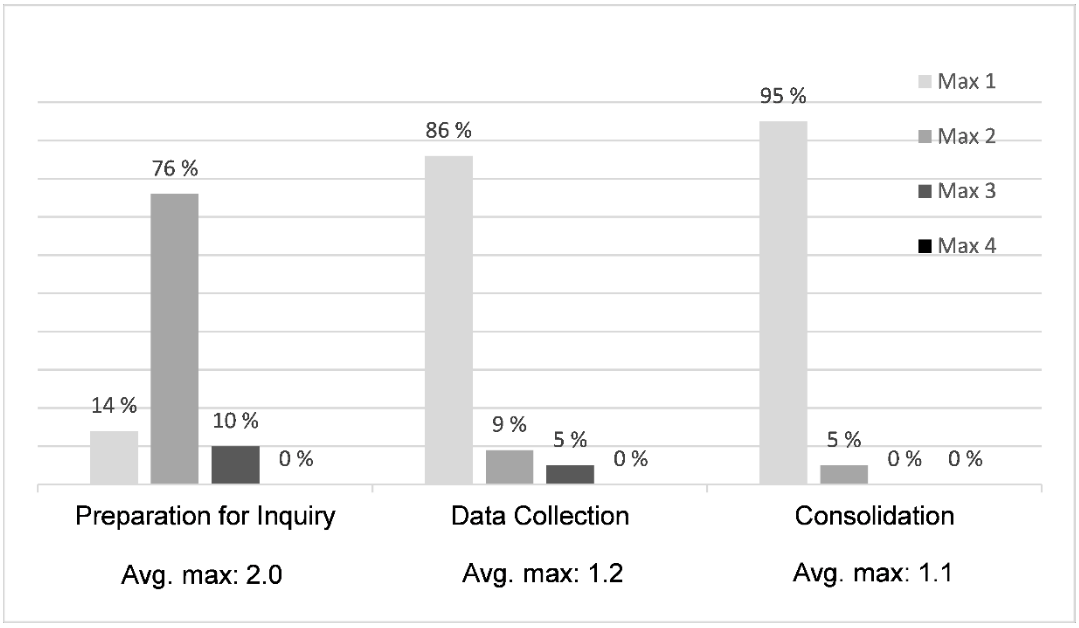
41% of all segments included students interacting with objects other than materials for reading and writing and were coded more than 1 on *practical activities* (Fig 4). 76% of the segments with practical activities received high-end scores, as they were focused on science concept learning. Practical activities were enacted in all phases of lessons, but typically towards the end. One example is the last segment of lesson 8, which concerned the energy content in food. In this segment, the students had to choose between eating a portion of potato chips or carrot and later burn the equivalent energy by jumping on their chairs. The PST analogized the activity to everyday knowledge about cars requiring refueling to drive. By linking the activity to this explanation, the PST helped students to learn the concept of energy content in food.

Inquiry teaching was seldom or poorly implemented

Preparation for inquiry, data collection and *consolidation* (Fig. 6) represent significant phases of inquiry teaching (Knain & Kolstø, 2019; Ødegaard et al., 2014). As inquiry teaching typically spans over a period of time, and not always follow a fixed order, the results for these categories are discussed at the lesson level (N = 21). For the preparation phase, a score of 2 indicated that PSTs activated students' prior knowledge or initiated activities where students wondered about science. This had the potential to initiate inquiry work. A score of 2 for *preparation for inquiry* was awarded in 76% of the lessons. Higher scores, which required formulation of researchable questions, hypotheses, or predictions, were awarded to only 10% of the lessons. In regard to the two other categories, just three lessons (14%) included data collection (score of 2–3), and in one lesson, students made simple descriptions based on collected data (score of 2 on *consolidation*). This means that, according to the definitions and standards we have used, we found little evidence for inquiry teaching.

Figure 6

Scientific inquiry, phases of inquiry teaching



Note. The coding for categories within the dimension cognitive activation. The coding represents the maximum score per lesson (N=21). Max 1 = percentage of lessons with 1 as the highest score, Max 4 = percentage of lessons with 4 as the highest score. Avg. max: average maximum score across all lessons.

Discussion

With this study, we contribute to the field with a video study of pre-service teachers' (PSTs) science instruction in school practica. An evidence-based manual was useful in analysis of targeted classroom actions. Chan and Hume (2019, p. 20) described that pedagogical content knowledge (PCK) may be studied as embedded in teaching practice. In the current study, the dimensions of quality instruction under study are grounded in PCK (Park et al., 2011). Thus, our case study may be viewed as an investigation of PCK embedded in teaching practice. For example, the category *feedback* represents practices that build on knowledge about students' understanding (PCK component) on which to give feedback, and which strategy of feedback would best facilitate the student's learning (PCK component). In the following, we discuss the coding results along the four dimensions of instructional quality.

Cognitive activation

We found that students were seldom provided challenging tasks that prompted them to improve their thinking. A beginning increase in cognitive activation from first to second round of data collection indicate PSTs' ability to develop, and impact from teacher education between the two school practica. From our data, quality classroom discourse seemed to facilitate intellectually demanding instruction. All the segments that achieved high-end scores for *intellectual challenge* (N=14) also received high-end scores for *classroom discourse* (Avg. 3,6). Cognitively activating discourse is known to be particularly important for students' cognitive engagement, since students get the opportunity to explain and justify their thinking (Smart & Marshall, 2013). Based on the finding of little intellectual challenging instruction in the current study, together with earlier studies on PSTs (Todorova et al., 2017) and in-service teachers (Turner & Meyer, 2004), we call on teacher educators to model for PSTs the difficult practice of giving demanding tasks. Particularly, beginning lessons with demanding tasks is found to deepen students' engagement in science (Kang et al., 2016).

Discourse features

Students were given a central role in the classroom discourse. In more than half of the lessons, the PSTs did not orient the lessons mainly around themselves. And in more than one of four segments the PSTs consistently acted as facilitators. In a dialogic, interactive approach to classroom discourse, student contributions are prompted, and an open conversation is facilitated (Scott et al., 2006). Results from the *classroom discourse* category describe more evidence for dialogic classroom discourse. Across all segments, the average score was 2.8 of

4. This represents a contrast to a video study of experienced teachers, being scored at 2.2 out of 7 on a similar category (Gamlem, 2019).

Instructional clarity

The PSTs struggled to communicate science content knowledge accurate and clear through representations, implementation of scientific language, and specific feedback on students' work or ideas. In many segments, the PSTs provided no, inaccurate, or even misleading representations of science content. This was especially true for in-depth lessons, for which only 6% of segments received high-end scores for *representation of content,* and in unplanned interactions. Although exemplary representations were also identified, these seemed to be concentrated in lessons that were not classified as in-depth, and during planned presentations. Further, *use of academic knowledge* received low-end scores in 69% of the segments, indicating that PSTs failed to either use or explain scientific terms. We identified misconceptions being passed on to students, which aligns with prior research on PSTs misconceptions (Kind, 2014; van Driel et al., 2014). The PSTs' poor presentation of content is likely related to their status as beginner PSTs with no prior higher science education. We suggest that teacher education course instructors give priority to teaching difficult topics relevant for school practica. Teachers need domain specific knowledge in the forms of content knowledge and pedagogical content knowledge (PCK) is necessary to support students' learning (Seidel & Shavelson, 2007). Further, our case study indicates the need for mentor teachers to focus on instructional clarity also in unplanned interactions in science classes.

The PSTs contributed to instructional clarity with their use of practical activities in teaching science concepts. This indicates that the participating PSTs avoided a common mistake of science teachers: initiating hands-on-activities without simultaneous connection to science ideas (Abrahams & Millar, 2008; Hofstein & Kind, 2012). Our results also contrast a

Norwegian video study (Ødegaard & Arnesen, 2010) that found in-service teachers use few practical activities and miss opportunities for scientific discussions during practical work.

Inquiry teaching

Inquiry teaching have significant potential in regards to student learning of science content knowledge, enculturation in to scientific practices, and is central in science education reforms (Crawford, 2014; Norwegian Directorate for Education and Training, 2020). The near absence of it in participants’ school practica is notable. We did observe *potential* for scientific inquiry as students were prompted to share prior knowledge and to wonder about science, but the potential was not exploited by the PSTs. This finding is similar to studies of in-service science teachers, reporting that students in general seldom work to investigate researchable questions (Crawford, 2014; Ødegaard, Kjærnsli, Karlsen, Kersting, et al., 2020), and specifically with the consolidation phase (Ødegaard et al., 2014). There seems to be a need for further studies and debate on why a potential for inquiry is difficult to exploit in science classrooms.

Conclusion and implications

We have described characteristics of science teaching along the four dimensions of instructional quality, for all six participating PSTs. Looking across the results, the PSTs’ instruction has certain characteristics of quality teaching, while other areas are weaker. Teacher education reform bring about a change from teacher-centered to student-centered teaching (Anderson et al., 1994; Sawada et al., 2002). One overarching quality of the teaching observed in this study was the PSTs’ centering of instruction around students’ ideas and interests rather than around the teacher. This was evident as the participating PSTs (a) organized their classes with frequent group work as well as whole-class discussions, (b) facilitated student–student talk, (c) elicited and connected to students’ prior knowledge or experiences, and (d) facilitated high-quality discourse in which students' contributions were valued. These indicators of student-centered teaching surprised us since many studies on beginner PSTs highlight their lack of ability to focus on student learning (Kagan, 1992; Körkkö et al., 2016; Mellado, 1998) and activate students' thinking (Ratinen et al., 2015). Along with student-centered teaching, the positive finding of these six PSTs targeted use of practical activities should remind teacher educators about the potential for PSTs to carry our quality science instruction. The PSTs participating in the current study, and possibly others, should not be treated as blank slates that need to be filled with knowledge and formed to teachers from scratch by teacher educators. Future research should further investigate sources of PSTs' development of quality instructional practices.

We also identified specific challenges faced by the participating PSTs when teaching science. Many of these challenges may be related to limited science content knowledge or knowledge of instructional strategies (PCK). Students were not sufficiently challenged intellectually, PSTs hardly enacted any inquiry teaching, scientific language was poorly explained, and representation of content varied too much in quality. One possible implication is to target efforts in teacher education programs towards the topics to be taught in school practica. This may provide PSTs with opportunities to both gain and make use of knowledge related to teaching specific science topics, leading to quality learning opportunities for students in practicum classrooms. The increase in cognitive activation from first to second school practicum indicates that the participating PSTs made use of the specialized science courses. Finally, if the intention is to orient science learning around inquiry, an increased focus across all teacher education components seems necessary.

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Supplemental material A

Table S1: Average scores for all segments per PST

Category	PST1	PST2	PST3	PST4	PST5	PST6
Number of segments	8	14	8	13	11	17
Cognitive activation						
Connections to prior knowledge	2.4 (4)	2.3 (4)	1.9 (3)	1.8 (4)	3.6 (4)	1.9 (4)
Intellectual challenge	1.8 (4)	1.8 (3)	2.4 (4)	1.9 (4)	2.3 (4)	1.8 (3)
Student reflection	1.3 (3)	1.1 (3)	1.0 (1)	1.2 (2)	1.4 (3)	1.0 (1)
Discourse features						
Teacher role	1.9 (4)	2.2 (4)	1.9 (4)	1.5 (4)	1.9 (4)	3.3 (4)
Classroom discourse	2.5 (4)	2.6 (4)	3.0 (4)	2.8 (4)	3.3 (4)	2.5 (3)
Instructional clarity						
Representation of content	1.6 (2)	2.1 (4)	1.5 (2)	2.2 (3)	2.5 (4)	1.4 (3)
Use of academic language	2.8 (4)	2.1 (3)	2.3 (4)	2.6 (4)	2.7 (4)	2.2 (4)
Practical activities	2.1 (4)	1.8 (4)	2.4 (4)	1.5 (4)	1.0 (1)	2.6 (4)
Feedback	2.0 (3)	2.4 (3)	2.0 (4)	2.2 (3)	2.5 (3)	2.2 (3)
Scientific inquiry						
Preparation for inquiry	1.5 (2)	1.6 (2)	1.1 (2)	1.5 (3)	1.6 (2)	1.4 (3)
Data collection	1.0 (1)	1.4 (2)	1.0 (1)	1.0 (1)	1.0 (1)	1.6 (3)
Consolidation	1.0 (1)	1.0 (1)	1.0 (1)	1.0 (1)	1.0 (1)	1.1 (2)
Average for all categories	1.8	1.9	1.8	1.8	2.1	1.9

Note. The table presents average scores across all segments for each PST, with maximum scores in parentheses. The total number of segments is 71.

Paper 2: Pedagogical content knowledge integration

Sæleset, J., & Friedrichsen, P. (2021). Pre-service science teachers' pedagogical content knowledge integration of students' understanding in science and instructional strategies. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(5). https://doi.org/10.29333/ejmste/10859

EURASIA Journal of Mathematics, Science and Technology Education, 2021, 17(5), em1965
ISSN:1305-8223 (online)
OPEN ACCESS
Research Paper
https://doi.org/10.29333/ejmste/10859

Pre-service Science Teachers' Pedagogical Content Knowledge Integration of Students' Understanding in Science and Instructional Strategies

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Received 18 August 2020 ▪ Accepted 25 February 2021

Abstract

In the current study, we address calls for research on the complex nature of integrations of pedagogical content knowledge (PCK) components. This is a multiple case study of six middle-school pre-service teachers (PSTs) as they taught science in their school practicum. We investigated the nature of PSTs' integration between knowledge of students' understanding (KSU) and instructional strategies (KIS), and their sources of these integrations. The primary data sources were two video stimulated recall interviews during which each PST viewed video recordings of their instruction, and shared reflections on their teaching. Results were represented as PCK maps. The PSTs frequently demonstrated integration of KSU and KIS, often developing topic-specific strategies. Instructional strategies served a variety of goals in response to students' needs. PSTs referred to specialized science content courses, peer PSTs, learning experiences, and mentor teachers as sources that contributed to the integrations. Implications for research and teacher education are included.

Keywords: instructional strategies, knowledge of students, pedagogical content knowledge, pre-service teachers, science education, teacher education

INTRODUCTION

Pedagogical content knowledge (PCK) is a useful framework for unpacking the complexities of science teachers' knowledge (Shulman, 1986) as evidenced in its use in a wide range of teacher research, including science teacher learning progressions (Friedrichsen & Berry, 2015; Schneider & Plasman, 2011), sources of teachers' professional knowledge (Kind, 2009; Nilsson, 2008), and the role of beliefs in teacher knowledge and practice (Friedrichsen et al., 2011). PCK consists of multiple components that inform each other, making PCK more than the sum of its components (Abell, 2008; Magnusson et al., 1999). Researchers have explored the integration among PCK components and found knowledge of students' understanding of science and instructional strategies to be the most central and frequently occurring integration, critical to teacher knowledge development (Akin & Uzuntiryaki-Kondakci, 2018; Chan & Hume, 2019; Park & Chen, 2012; van Driel et al., 2002, 2014).

This study addresses calls for research on the complex nature of integrations among PCK components (Akin & Uzuntiryaki-Kondakci, 2018; Brown et al., 2013), particularly how teacher education programs facilitate the development of PCK integration (Aydin et al., 2015). In this study, we investigated six pre-service teachers' (PSTs) PCK integration of knowledge of students' understanding in science (KSU) and knowledge of instructional strategies (KIS).

Through a fine-grained analysis of PSTs' reflections on their teaching, this study extends prior insights into integration of KSU and KIS. Our study was closely connected to teachers' practice through the use of stimulated recall interviews (SRI) where video recordings of their instruction were used to prompt PSTs' reflections. Further, we address the call for research on the role of teacher education programs through analysis of PSTs' sources of integrated PCK.

The following research questions guided the study: 1) What is the frequency and nature of PSTs' integration of

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Contribution to the literature

- In this study, pedagogical content knowledge (PCK) maps (Park & Chen, 2012) are used to investigate integration of knowledge of students' understanding and instructional strategies at a new level of detail.
- Contradicting the few prior studies on pre-service teachers' PCK integrations, we show empirical evidence of their frequent and complex integrations.
- Few other studies have investigated the sources of integrations between knowledge of students' understanding and instructional strategies. The current study addresses the little investigated question regarding which sources PSTs draw on when integrating KSU and KIS.

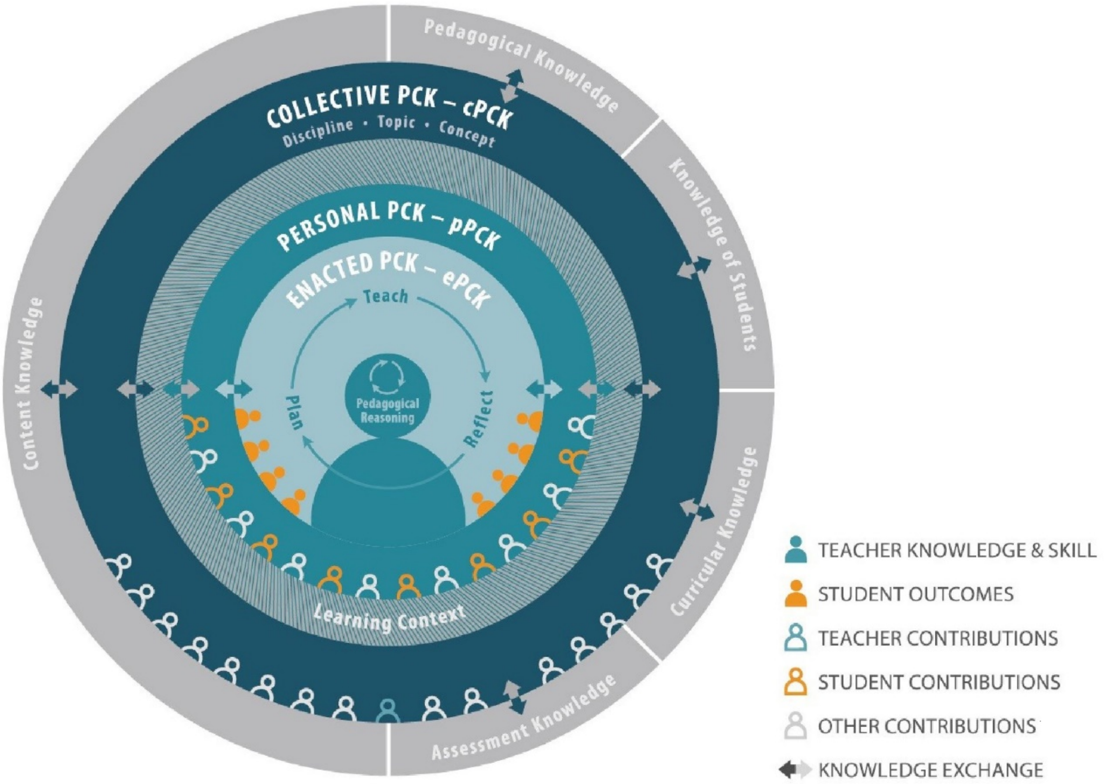

Figure 1. The Refined Consensus Model (RCM). Reprinted by permission from Springer Nature *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* by Hume, A., Cooper, R., & Borowski, A. (Eds.) COPYRIGHT 2019

the PCK components KSU and KIS? 2) What are the sources that contribute to their PCK integration?

Theoretical Framework

PCK, originally defined broadly as specialized knowledge for teaching, serves as a conceptual framework for this study (Shulman, 1987). Recently, PCK has been defined as:

> What teachers know about how their students learn specific subject matter or topics and the difficulties or misconceptions students may have regarding this topic related to the variety of representations (e.g., models, metaphors) and activities (e.g., explications, experiments) teachers know to teach this specific topic (van Driel et al., 2014, p. 849).

The assumption we build on is that teacher cognition is reflected in teaching practice; reciprocity exists between teacher cognition and teaching activities (van Driel et al., 2014).

In science education, Magnusson et al. (1999) conceptualized PCK as consisting of four components: knowledge of science curricula, knowledge of students' understanding in science, knowledge of instructional strategies, and knowledge of assessment of scientific literacy. Each of these four components is influenced by the teachers' science teaching orientation. The Refined Consensus Model (RCM) (Figure 1) situates PCK within other knowledge bases, and presents three realms of PCK: enacted PCK (ePCK), personal (pPCK), and collective (cPCK) (Carlson et al., 2019). Personal PCK (pPCK) is ´specialized knowledge and set of skills for teaching particular science topics for particular students in particular learning contexts´ (Carlson et al., 2019, p.

86). Enacted PCK (ePCK) is pPCK in action in a particular situation. Both these realms exist within the context of the educational climate, classroom environment, and individual student attributes. Collective PCK (cPCK) is the amalgam of the education community's knowledge across contexts, and is located across a continuum of groups, from teachers working in a professional learning community to canonical PCK accessible in the research literature. Arrows connecting the circles represent knowledge exchange. This exchange is amplified or filtered through teachers' attitudes and beliefs including beliefs about students, the nature of science knowledge, or the role of the teacher (Carlson et al., 2019). In the current study, PSTs' ePCK occurred in their field practicum, and was observed by the first author. All three realms can be viewed at different levels, i.e., discipline-specific, topic-specific, or concept-specific PCK. From the RCM, we use the distinctions of ePCK, pPCK and cPCK. We draw upon the Magnusson et al. (1999) model for PCK components, focusing on KSU and KIS. We focus on integration of PCK components as this is a hallmark of high quality PCK and a key to effective science teaching (Abell, 2008; Chan & Hume, 2019).

Literature Review: Integration of PCK Components

We summarize key research on teachers and PCK integration, and how teacher education programs can support the development of PCK integration. Generally, researchers have reported that PSTs have little PCK (Kind, 2009; Schneider & Plasman, 2011; van Driel et al., 1998). However, a few studies have found initial PCK of PSTs, mainly KSU. In a Swedish study of PSTs' conceptions about students' topic-specific difficulties, 32 PSTs did a lesson preparation task (Kellner et al., 2011). Collectively, they were able to identify many student difficulties. In another study of 12 pre-service chemistry teachers in a postgraduate program, de Jong et al. (2005) reported initial PCK of learner difficulties, formed by experiences from school, university, teaching experience, and textbook study. After a course module connecting authentic teaching experiences with university-based workshops, all PSTs demonstrated a deeper understanding of students' learning difficulties.

As integration of PCK components is a key to effective science teaching, PCK components should be integrated in planning and enactment of instruction (Chan & Hume, 2019; Park & Chen, 2012). An example of PCK integration would be a teacher choosing a particular instructional strategy (e.g., demonstrating meiosis using multiple pairs of socks) because he is aware of particular student learning difficulties (e.g. students have difficulty distinguishing between homologs and replicated chromosomes). Developing PCK integrations includes increasing frequency of integrations between specific components, or increasing types of integration of PCK components. Researchers reported relationships between the development of separate components and integration among components (van Driel et al., 2014). As they generally lack PCK, it follows that PSTs also lack integration of PCK components (Akin & Uzuntiryaki-Kondakci, 2018; Kind, 2009; Sickel & Friedrichsen, 2018).

In contrast to PSTs, research has found experienced, exemplary teachers to have highly integrated PCK (Park & Chen, 2012). Timmerman (2009) found Dutch experienced biology teachers used their knowledge of students as the primary source of information in their sex education lessons. KSU and KIS were also integrated during lessons, as instruction was adjusted based on what they learned about students' conceptions. In a recent study, Akin and Uzuntiryaki-Kondakci (2018) found experienced teachers to have more integrated PCK than novice teachers. They analysed one novice and two experienced teachers' instruction of the same lesson plan on reaction rate and chemical equilibrium. Their findings indicated the PCK maps of the novice teacher had fewer connections among PCK components, while the experienced teachers integrated all PCK components. The experienced teacher's knowledge about students and instructional strategies seemed to foster the integration of these components. The experienced teachers were also better able to enact their integrated PCK (Akin & Uzuntiryaki-Kondakci, 2018). Further, West (2011) found that the three experienced, physics teachers in his study integrated all components of their PCK in selecting representations.

However, there are a few studies that show that PSTs can begin to integrate PCK components. Schneider (2015) found that PSTs frequently think about instructional strategies and student thinking together in planning, enactment, and reflection upon instruction. Also, Kaya (2009) analysed survey data on 75 PSTs' PCK for the topic *ozone layer depletion*. He identified relationships among PCK components, specifically among knowledge of science curricula, instructional strategies, and student understanding. Recently, Mavhunga (2020) studied PSTs' content representations (CoRes) and lesson outlines for the topic *chemical equilibrium*. The 15 participating PSTs were in their latter part of a teacher education program, and used multiple components of topic-specific PCK in connection when planning for teaching chemical equilibrium. However, it should be noted that neither Kaya (2009) or Mavhunga (2020) studied enacted PCK across the whole pedagogical cycle.

In regard to development of PCK integration during teacher education programs, studies are limited. However, available research indicates that teaching experience and reflection are essential. In a qualitative in-depth study of PSTs, van Driel et al. (2002) reported KSU and KIS developed through classroom experiences, discussions with a mentor teacher, and PCK-specific university-based workshops. Brown et al. (2013) carried

Table 1. Differences between current study and Park & Chen (2012)

Difference	Park & Chen (2012)	Current study
PCK model	Pentagon model (Park & Oliver, 2008)	Magnusson et al. (1999)
Participants	Four in-service high school teachers	Six pre-service middle school teachers
Data sources	Observations, pre- and post-interviews, documents	Stimulated recall interviews based on video recordings of classroom teaching
Unit of analysis	PCK episode constituted by enactment of instructional strategy with PCK integration	Instructional segment constituted by enactment of instructional strategy
Analysis	Overview of integrations among KSU, KIS, KAs, KSC and OTS	Detailed analysis of integration of KSU and KIS, including the rationale for enacting the instructional strategy
Selected findings	KSU and KIS were central in the integration	Identified mechanisms and sources of KSU-KIS integrations

Abbreviations from Magnusson et al. (1999). KSU: Knowledge of students' understanding in science, KIS: Knowledge of instructional strategies, KAs: Knowledge of assessment of scientific literacy, KSC: Knowledge of science curricula, OTS: Orientation to teaching science

out a study of four pre-service biology teachers in an alternative post-baccalaureate teacher education program. The authors reported that the PSTs' KSU and KIS, specifically the use of the 5-E instructional model (Bybee et al., 2006), became more integrated during the program. This study suggests that the development of PCK components and integration develop simultaneously during student teaching. In another study, researchers found that pedagogical instruction framed by PCK for Nature of Science (NOS) to some degree enhanced PSTs' readiness to integrate components of PCK. PSTs with integrated PCK were better able to design instruction that addressed students' misconceptions about NOS (Demirdöğen et al., 2016). Moreover, in a recent study Barendsen and Henze (2019, March 31–April 3) studied the interplay among elements of PK and PCK in pre-service chemistry teacher education. They found that complex pedagogical reasoning involving KSU and KIS seemed to appear in combination with strong pPCK development. In a qualitative study of three PSTs, Aydin et al. (2015) reported increased integration of PCK components through a PCK-enriched 14 week practicum course. Connections between knowledge of science curriculum and the other components were rare in the beginning of the program, but integration of knowledge of science curriculum developed more than other integrations in the course of the program which the authors attribute to a focus on curriculum in the practicum.

Teaching experience can contribute to development of PCK (Grossman, 1990; Sorge et al., 2019). Norville and Park (2019, March 31–April 3) investigated PSTs' development of PCK during a student teaching experience. From integrating little PCK of KSU and KIS at the beginning of the semester, this integration increased for each of the four PSTs at the end of the semester. Sickel and Friedrichsen (2018) examined early-career biology teachers' nature and integration of PCK components across two years for the topic of natural selection; they identified the teachers developed more integrated PCK for this topic over time. In their study of the role of teaching experience in the absence of teacher education, Friedrichsen et al. (2009) compared two pairs of teachers at the beginning of a teacher education program. One pair had prior teaching experience as uncertified teachers (1-2 years) while the other pair lacked any teaching experience. Neither of the pairs had topic-specific PCK for heritable variation. When the authors analysed the teacher's pedagogical knowledge (PK), using the same Magnusson et al. (1999) components, they found that teaching experience did result in more PK integration, but not PCK development in the absence of teacher education. For example, the participants with teaching experience knew that students struggled in general with science (KSU), so they often had students work in pairs (KIS).

The current study addresses calls from Akin and Uzuntiryaki-Kondakci (2018) and Aydin et al. (2015) for more research investigating the strength and quality of PCK component integrations. In their literature review, van Driel et al. (2014, p. 859) concluded that ´questions related to what PSTs do with their PCK and how practice interacts with PCK so far remain largely unexplored.´ The RCM model acknowledge teachers' actions as a realm of PCK (ePCK), and underline a need for research connected to actual teaching practice (Carlson et al., 2019). Specifically, a better understanding of PCK development is needed to inform the design of effective teacher education programs that facilitate PCK integration (Jong et al., 2005). By including lessons on sexual health, we add to the few studies of PCK for teaching sexual health (Timmerman, 2009). Our study addresses these gaps by mapping out the nature of integrations and analysing sources of integrated PCK. Such a methodology using complementing quantitative and qualitative analysis has seldom been used in PCK research (Krepf et al., 2018).

METHODS

Research Design

This is a qualitative multiple case study (Yin, 2014) of six PSTs in the context of their school practicum as part of a teacher education program. Multiple case studies examine the cases with a broader goal to provide insight

Table 2. Teacher Education Program Grade 5-10

Year	15 ECTS	15 ECTS	15 ECTS	15 ECTS		Practicum
Year 1	Science (joint elementary and middle school PSTs)	Science	Subject 3	P&S (10)	R&D (5)	Field practicum, 3+3 weeks
Year 2	Subject 2 (joint elementary and middle school PSTs)	Subject 2	Subject 3	P&S (10)	R&D (5)	Field practicum, 3+3 weeks
Year 3	Science (20)	Subject 2 (20)	R&D (5)	R&D thesis		Field practicum, 3+3 weeks
Year 4	P&S	P&S	Science, master course	Science, master course		Field practicum, 4+2 weeks
Year 5	Research methods	Master thesis in science pedagogy				–

Science = Subject 1. P&S: Pedagogy and students. R&D: Research and Development. 60 ECTS = one-year full-time study. ECTS in brackets when differing from columns

into an issue or redraw a generalization (Stake, 2005). In the current study, we examine how integration of KSU and KIS occurred in their enacted PCK, and how this integration developed in their personal PCK. The research design was informed by the PCK integration research of Park and Chen (2012) (Table 1).

Context

In Norway, many teacher education programs have recently shifted from four-year undergraduate programs to five-year Master of Education programs. The longer programs were initiated to provide PSTs with greater depth of content knowledge, teaching methods, and research with the goals of increasing student learning outcomes and giving more status to the teaching profession (Ministry of Education and Research, 2009; Olufsen et al., 2017). In this study, the specific teacher education program certified middle school teachers (grade 5-10, ages 10-16). In each year of the program, PSTs completed specialized content courses focusing on both content and pedagogy of three school subjects of choice (Subject 1, 2, and 3, see Table 2). The specialized content courses focused on content knowledge, while PCK was addressed through course instructors' modeling of reform-oriented instructional practices, and by explicitly focusing on K-12 students' common misconceptions related to the topic. Subject 1 was the main subject and included a 45 ECTS master thesis (In European Credit Transfer and Accumulation System, 60 ECTS is equivalent to one-year full-time study). Alongside these subject-specific courses, all PSTs took courses in Pedagogy and Student Knowledge (P&S) and Research and Development in education (R&D). These courses covered general pedagogical knowledge, additional teaching methods, and educational research. Each year included six weeks of field practicum, approximately three weeks of full school days in each of the fall and spring semesters. Table 2 provides an overview of the program. Specialized science course curricula were aligned with the national science curriculum for Norwegian primary and lower secondary schools, including chemistry, physics, geology, biology, health, and Technology & Design (UiT Norges Arktiske Universitet, 2016). Health, including sexual health, is included science curricula in some countries, such as in the Netherlands (Timmerman, 2009), New Zealand (Diorio & Munro, 2000), England (Department for Education, 2014), Finland (Mullis et al., 2015), and Norway (Norwegian Directorate for Education and Training, 2013). Sexual health education relates to biological aspects as well as socio-emotional and relational aspects (Timmerman, 2009), and is therefore covered in science lessons, among others. Central topics such as biological changes during puberty and the menstrual cycle are based on biology. During the first year in the teacher education program, participants' specialized science courses focused on biology in the intertidal zone, basic geology, waves and sound, the solar system, sexual health, technology & design, and science pedagogy. The first author taught two units (the solar system, waves and sound) for a total of 12 hours. To avoid conflicts of interest with the research study, the first author did not participate in formal assessment of the PSTs in these two units. In their Research and Development course (R&D), the PSTs learned about the nature of science, educational research, and classroom leadership. Their Pedagogy and Students course (P&S) provided the PSTs with an overview of educational law and curricula, insight into how students aged 10-16 learn, and experience in planning, enactment, and assessment of instruction (UiT Norges Arktiske Universitet, 2016).

Participants

From one cohort entering the middle school teacher education program, all PSTs who had chosen science as their subject 1 (16 PSTs) were invited to participate in the study; 12 of the PSTs gave their consent. The cohort was organized in field practicum groups by university administration. In order to be able to be present in the PSTs classrooms as much as possible, we wanted to study a few PSTs concentrated in a few field practicum groups. We requested that the administrator organize some of the groups with three PSTs who had given consent to participate in the study and had chosen science as their subject 1. The administrator, restricted by

Table 3. Participants

Pseudonym	Years of high school specialized science	Teaching-related experience
Ingvild	2 years biology, 2 years chemistry, and 2 years technology and research	Leader of leisure activities for 9-10 year old kids
Jens	None	None
Sanna	1 year advanced mathematics, 2 years chemistry, and 2 years geology	Leader of leisure activities for 15-18 year old kids
Jakob	2 years biology	Leader of leisure activities for 5-17 year old kids
Pia	None	Substitute teacher, immigrant language training
Lena	None	Children and youth worker. Practicum in lower secondary school for 6 months, in kindergarten 1.5 years

Table 4. Science topics taught in school practica

PST	Field practicum school	Topics field practicum 1, fall semester	Topics field practicum 2, spring semester
Ingvild	School 1	**Nutrition**	**Sexual health***
Jens		**The eye**	Animals, nutrition, **drugs**
Sanna		**Energy content in food**	**Sexual health***
Jakob	School 2	**Male puberty***	Energy, **energy and fuel,** energy sources
Pia		**Female puberty***	Renewable energy, **fossil fuels**
Lena		**Puberty***	**Energy, Technology & Design***

* = Taught at the University prior to the lesson in field practicum. Topics in bold: Lessons followed up by interviews

various factors, was able to organize two such groups. These six PSTs, aged from 19-24 years, were the participants in the study (See Table 3). As Table 2 indicated, PSTs focused on science and subject 3 in Year 1 of the program. The administrator aspired to recruit mentor teachers teaching science and some of the other subjects which PSTs in the two practicum groups had chosen as their subject 3. In cooperation with the school practicum administrator, two of the experienced local mentor teachers with the preferred teaching subjects were recruited.

Three of the PSTs, Ingvild, Jens, and Sanna (pseudonyms), were placed at school 1, in a grade 7 classroom (11-12 years old). Out of the 32 students, 69% were Norwegians and 31% from the East, Middle East, or Africa. The mentor teacher was a female with more than 10 years of experience. She was not certified in science but enjoyed teaching science. The other PSTs, Jakob, Pia, and Lena (pseudonyms), were placed at school 2, in a grade 6 classroom with 20 students (aged 10-11 years) of which all were Norwegians. The male mentor teacher had more than 10 years of experience and had science as a part of his initial teacher education. Within both groups, PSTs and their mentor teacher discussed lesson plans and issues regarding instruction, and they observed each other's instruction. Both mentor teachers focused at issues regarding general pedagogy and taking account of the diversity of students. Selecting science topics for PSTs to teach was mentor teachers' responsibility. PSTs were allowed to make their own choices on how to teach those topics. The school contexts and topics taught by each PST are described in Table 4.

Data Sources

The primary data source was two video stimulated recall interviews (SRI) from each of the six participants, revealing both reflection-in-action and reflection-on-action (Meade & McMeniman, 1992). Using SRIs is a purposeful strategy to understand not only what teachers do (the what), but also their rationale for doing so (the why) (Gess-Newsome, 2015; Henderson & Tallman, 2006). Each PST was interviewed within three hours after two of their lessons in their school practicum. These lessons were selected by matching the researchers' and PSTs' schedules and identifying two available science lessons which also allowed for a SRI shortly afterwards. In the SRIs, the first 20 minutes of instruction were viewed in its entirety and the PST was instructed to pause the video every time she recalled any thoughts or feelings from the lesson. The first author then advanced the video to selected lesson events which related to students (e.g., when a student comment reveals a misconception) or instructional strategies (e.g., when PST assign students a specific task). As a response to PSTs sharing of reflections, the first author asked follow-up questions, which included both general prompts like 'Tell me more about what happened here,' and specific questions like 'What did you think the student thought here' or 'Tell me why you chose to use this activity.' Sources were elicited through asking 'From where have you got knowledge about this?' Each interview lasted 60-90 minutes.

Data Analysis

The data analysis process examined integrations of KSU and KIS at the levels of topic-specific PCK, discipline-specific PCK, as well as general PK. General PK, while separate from PCK, was included to give a more complete picture and more detailed analysis of the knowledge PSTs drew on. For simplicity in showing integration, all the levels are located within the categories of KSU and KIS. SRIs were transcribed using QSR International's NVivo 12 Plus software (2018). The interviews, along with the corresponding audio of the video-recordings of the lesson, were transcribed. The data analysis description is organized by research question.

Research Question 1

Step One. The SRI transcripts were divided into instructional segments. An instructional segment is defined as a section of the interview and video lesson transcripts related to a particular instructional strategy (e.g., PST verbally explains electric current to a student) or other distinct phase in instruction such as specific example within the use of an instructional strategy (e.g., answering one of several anonymous questions from the students about puberty) or changing focus to a different student. Instructional segments had an average length of approximately four minutes.

Step Two. Instructional segments were analysed and assigned one or both of the codes *KIS* and/or *KSU*. Coding with *KIS* indicated that the segment included reflections about an instructional strategy. Coding with *KSU* indicated PST's reflections on individuals or groups of students in the segment. Reflections included in the coding could stem from lesson planning or enactment. Instructional segments coded to both *KIS* and *KSU* (hereafter called integrated segments) were re-read to ensure the components were integrated, and not just mentioned in the same segment. We also analysed whether *KSU* informed *KIS* in the segment. The integrated segments were analysed further in order to represent the diversity within the *KIS* – *KSU* integration, as described below in Step Three.

Step Three. First, integrated segments were assigned one or more subcodes in the category *KSU,* (i.e., *requirements for learning* and *areas of difficulty)* (Magnusson et al., 1999), as well as emerging inductive codes on *student characteristics.* Student characteristics included *science-specific student characteristics,* related to requirements for learning within PCK, and *general student characteristics*, related to PK. Both were essential parts of PSTs' knowledge of students critical to science instruction, and therefore included in our coding. Second, integrated segments were assigned one subcode within the category *KIS,* organized by *topic-specific* and *science-specific strategies* (Magnusson et al., 1999) as well as *general pedagogical strategies*. We define topic-specific strategies as developed and/or adapted for a specific science topic, while science-specific strategies are suitable across science topics. General pedagogical strategies are suitable across school subjects and were included in our coding to represent the full repertoire of instructional strategies implemented by the PSTs.

Step Four. Next, all integrated segments were inductively coded for *rationale*, which is the inferred reason for the instructional strategy used in the segment. For example, *student participation* was one subcode within the *rationale* category, and it was assigned when an instructional strategy seemed to be enacted to engage students. Another subcode was *application*, assigned when a strategy was used to apply scientific knowledge to students' lives. The first author coded all of the material, while both authors coded some transcripts to ensure accurate coding. When in doubt, both authors discussed the coding to reach agreement. In online Supplemental Table S1, we illustrate coding of an integrated segment.

Step Five. After all integrated segments were assigned subcodes from the three categories: *KSU*, *KIS* and *rationale*, the subcodes in both SRIs for each PST were summed up and represented as PCK maps. In prior research, PCK maps have been used to show integration at the category level (i.e., KSU, KIS) (Akin & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012; Park & Suh, 2019). Our maps differ in grain size and focus on integration at the subcode level. Regardless of length of the integrated segment, and whether double coding was based on larger parts of the segment or a single sentence, every double coding counted as one. The example map (Figure 2) shows for the case of Sanna, 20% or more of the total of 21 integrated segments were coded to *prior knowledge (KSU),* and *topic-specific representations (KIS)*. The integration of *prior knowledge* and *topic-specific representations* is represented with a thin, continuous arrow indicating that 10-14% of the 21 integrated segments were double coded to these subcodes.

Step Six. To complete the analysis of integrations, the PCK maps were analysed individually and across cases, similar to Park and Chen (2012). The authors visually identified common patterns and differences across the six PCK maps.

Research Question 2

To identify PSTs' sources of integration of KSU and KIS, each integrated segment was analysed for references to specific sources of the evident KSU or KIS, and the integrations of those. Codes for this analysis emerged from the data; some example codes include *personal learning experience, mentor teacher*, and *specialized science courses*. See online supplemental Table S2 for an example of how sources are coded to an integrated segment.

RESULTS

We present our results as four cross-case assertions. The first three assertions unpack the nature of the integrations of KSU and KIS based on the PCK maps. The final assertion relates to the identified sources contributing to the PSTs' integrations.

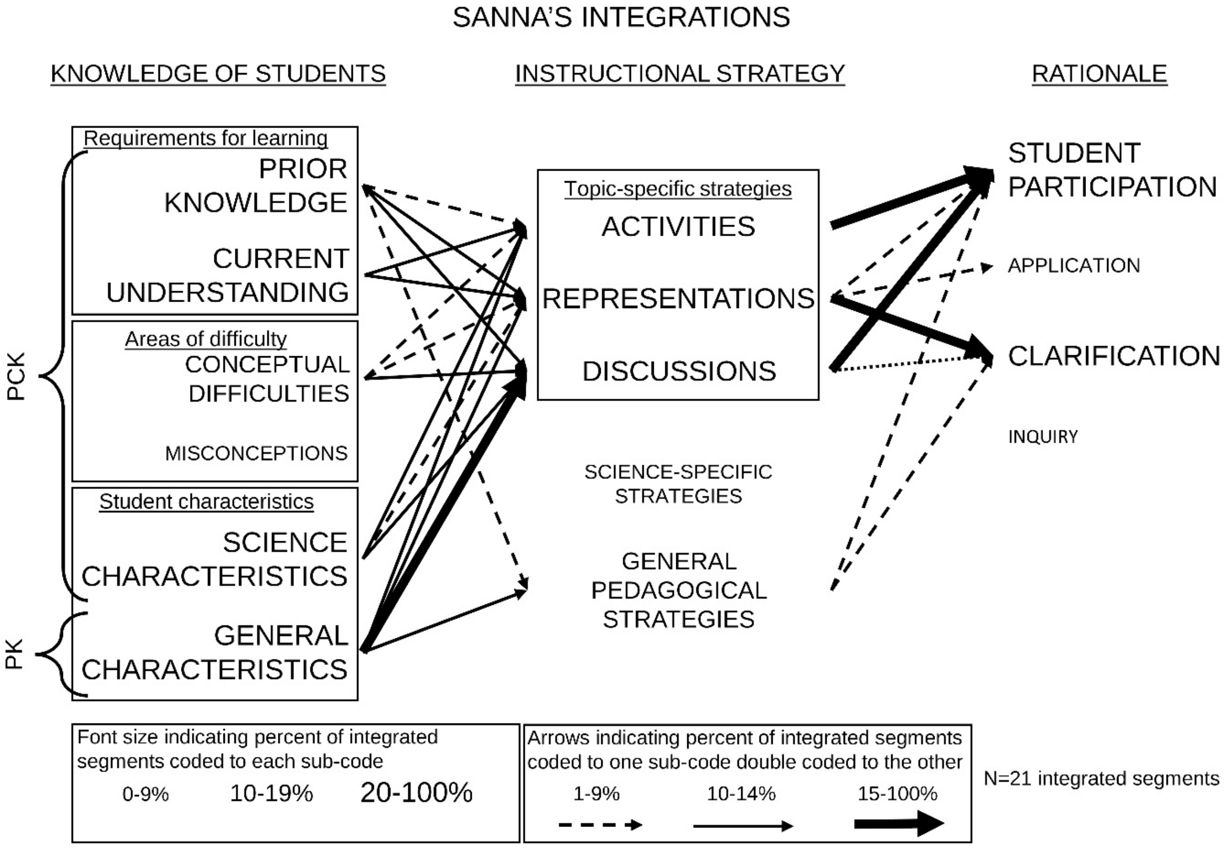

Figure 2. All integrated segment coding for Sanna, represented in a PCK map

Table 5. Instructional segments and integrated segments

Segments	Ingvild	Jens	Sanna	Jakob	Pia	Lena	All PSTs
Instructional segments	40	33	23	42	29	25	192
Percentage of integrated segments	93%	88%	91%	90%	93%	88%	91%
Percentage of integrated segments with KSU informing instructional decisions (KIS)	70%	52%	74%	69%	86%	72%	70%

Assertion 1: The PSTs Held Highly Integrated Knowledge of Students with Knowledge of Instructional Strategies

Among the 192 instructional segments identified across all the PSTs' interviews, 91% were integrated segments (Table 5). The PSTs were quite similar in this regard, with the individual percentages of integrated segments ranging from 88-93%. In the majority of the integrated segments (range of 52-86%), the PSTs were using their KSU to inform their instructional decisions. The decisions were at the topic specific PCK, science-PCK, and general PK levels. This indicates that they, despite being beginner PSTs, made efforts to tailor the science instruction based on the knowledge of students in general and their specific students.

Within the *KSU* category, one of the subcodes was *conceptual difficulties*. In one of Jakob's segments, he integrated knowledge of *conceptual difficulties* with KIS. He had searched online for proper illustrations of pimples, but the one he found was too complex for his purpose. He explained, 'It showed lots of skin layers, and I thought it would be too much *[Category: KSU, subcode: conceptual difficulties]*. I just want to limit it, just want them to focus on this (pimples) *[Category: KIS, subcode: topic-specific representations]'* (Jakob, SRI1). Jakob knew that his students would have difficulty understanding how pimples develop if he used a complex illustration. Therefore, he chose to draw his own simple illustration of skin with one hair follicle to show how pimples develop. In another integrated segment, Pia reflects on how her knowledge of student's *prior knowledge (KSU)* informed her choice to initiate a *topic-specific discussion* (*KIS*) about similarities between formation of peat and petroleum: 'Aud (student) clearly remembered peat as a renewable energy source, and all the others remember peat was built of multiple layers. We have to draw on that and compare to formation of oil and gas' (Pia, SRI2). In this example, Pia's knowledge of *prior knowledge* informed her initiative for a whole class *topic-specific discussion,* which next uncovered more *prior knowledge*.

The participant examples show integration of KSU and instructional strategies in which PSTs' KSU

Table 6. Coding to subcodes in the category of KSU. Percentages of PSTs' integrated segments

KSU subcodes	Ingvild	Sanna	Pia	Jens	Jakob	Lena
CK subcodes						
Prior knowledge	19 %	29 %	22 %	14 %	16 %	5 %
Current understanding	22 %	29 %	15 %	48 %	32 %	32 %
Conceptual difficulties	11 %	19 %	4 %	31 %	24 %	32 %
Misconceptions	3 %	0 %	11 %	14 %	13 %	14 %
Science-specific student characteristics	46 %	24 %	48 %	14 %	39 %	32 %
PK subcodes						
General student characteristics	24 %	52 %	48 %	17 %	18 %	50 %

informed their instructional decisions; this occurred in 70% of the transcribed instructional segments. Some of the integrations occurred during lesson planning, while other integrations occurred during enactment of the lesson.

Assertion 2: In the Integrated Segments, the PSTs Varied in their Emphasis within the Category of KSU. Some of the PSTs Focused on Requirements for Learning and Areas of Difficulty, while Others Focused on Student Characteristics

Within the integrated segments, PSTs reflected on a variety of aspects of KSU, represented by the emergent subcodes: *prior knowledge, current understanding, conceptual difficulties, misconceptions, science-specific* (PCK), and *general student characteristics* (PK). Integrated segments were often assigned multiple subcodes, indicating that the PST reflected on several subcodes of *KSU* within one instructional segment. PSTs' reflections were based on their knowledge of students in general and their specific students in the practicum classroom. Table 6 shows the percentage of their reflections for each subcode within *KSU.* Jens, Jakob and Lena reflected more than the other PSTs on students' conceptual difficulties and misconceptions (21% of their integrated segments on average, compared to Ingvild, Sanna, and Pia with 8% average). On the other hand, Ingvild, Sanna, and Pia reflected more than the other PSTs on student characteristics (40 % of their integrated segments on average, compared to Jens, Jakob and Lena with 28% on average). Examples of different foci within *KSU* follows.

First, a focus on conceptual difficulties and misconceptions is exemplified with reflections from Jens. In his instruction about the eye, he noted that a student misunderstood how the pupil responds to light. ´She did a mistake about when the pupil contracts and expands . . .. I don't think she really understood it´ (SRI1). The student believed the pupil expands with exposure to light. Jens recognized that this particular student held a misconception of how the pupil works. Jens focused on student misconceptions in 14% of his integrated segments. Second, a focus on student characteristics is exemplified with reflections from Ingvild. During her instruction about nutrients in food, she thought of how students would perceive that fish was the only source of unsaturated fat she used during instruction.

> I just mentioned salmon and fish. I thought I should mention, because I am not sure if there might be vegetarians among the students. Just to mention that you might find it [unsaturated fat] in avocado. Or if someone might not like fish, and I am sure there is, it is present in fruits and vegetables, too (Ingvild, SRI1).

By this example, Ingvild showed that she had topic-specific student characteristics in mind while teaching. In summary, data analysis revealed that the PSTs identified a broad range of students' requirements for learning, areas of difficulty and student characteristics. All categories of KSU were frequently discussed in integrated segments. This indicates their broad attention to students, rather than focusing on themselves and their teaching delivery.

Assertion 3: In the Integrated Segments, the Major of the Instructional Strategies were Topic-Specific; These Strategies were Used to Either Clarify the Science Content, Apply it to a Familiar Setting, or Engage Students

Instructional strategies are the teacher moves enacted in instructional segments. The participating PSTs demonstrated a limited range of instructional strategies. Overall, their instruction was discussion-based. Further, experiments were almost absent. In this study, however, our focus was to investigate integrations between KSU and KIS. We define topic-specific strategies as developed and/or adapted for a specific science topic, while science-specific strategies are suitable across science topics. General pedagogical strategies are suitable across school subjects and belong in the knowledge domain of PK. Percentages of integrated segments with each subcode of *KIS* are presented in Table 7. On average, 88% of instructional strategies in the integrated segments were topic-specific, 2% science-specific, and 10% general pedagogical strategies (Table 7). The emphasis on topic-specific instructional strategies applied to all the PSTs. Topic-specific activities were discussed in 20% of the integrated segments on average. These are tasks, demonstrations, simulations, enquiries, and experiments about specific science concepts or topics. The rationale for an instructional strategy is the inferred reason describing why the instructional strategy was

Table 7. Coding to subcodes in the category of KIS. Percentages of PSTs' integrated segments

KIS subcodes	Ingvild N=37	Jens N=29	Sanna N=21	Jakob N=38	Pia N=27	Lena N=22	All PSTs N=174
General pedagogical strategies (PK)	22 %	3 %	14 %	8 %	7 %	0 %	10 %
PCK instructional strategies							
Science-specific strategies	3 %	0 %	0 %	0 %	0 %	14 %	2 %
Topic-specific strategies	76 %	97 %	86 %	92 %	93 %	86 %	88 %
Subcodes of topic-specific strategies							
Topic-specific activities	19 %	31 %	24 %	8 %	15 %	32 %	20 %
Topic-specific representations	16 %	52 %	29 %	71 %	30 %	36 %	40 %
Topic-specific discussions	40 %	14 %	33 %	13 %	48 %	18 %	28 %

used. Each PST integrated at least one topic-specific strategy with each of the following rationales: *clarification*, *application*, and *student participation*. In his instruction about the eye, Jens used a topic-specific activity with *student participation* as rationale. He asked students to extend their arms more than 90º to the sides and observe that they could still see their arms. ´Video Lesson Transcript: If you hold your hands out like this, (both hands extended to the sides) you can see that you have side vision, slightly more than 180º actually´ (SRI1). Through this topic-specific activity, Jens helped students understand the concept of peripheral vision by actively involving the students.

Topic-specific representations were used in 40% of all PSTs' integrated segments. Topic-specific representations are illustrations, examples, models, and analogies about specific science concepts or topics. Jakob discussed topic-specific representations in 71% of his integrated segments, the highest percentage among the PSTs. In Jakob's instruction about male puberty, he projected a road construction sign on the screen as an analogy to illustrate that the human brain is reorganized during puberty. The rationale for using this representation was *application*. He wanted to apply the concept of changes in the brain during puberty to a familiar example, road signs. In this reflection, he explains why he used a sign as a representation.

> When they see (the road construction sign), they have something visual to connect to. It is not just words, but I talk about the brain and they see the roadworks sign. Then they can "OK, it is closed for the moment". Because I could almost talk about a road and pipes being moved around and stuff. They see that "Yes, things are remodelled here" (Jakob, SRI1).

The road construction sign served as a topic-specific representation (i.e., analogy) for puberty.

Topic-specific discussions are discussions of specific science content or topics. These include student-student talk and student-teacher talk about topic-specific issues. Topic-specific discussions were used in 28% of all integrated segments. Sanna used a topic-specific discussion in her instruction about sexual health with *student participation* as rationale. Students were asked to discuss which rules they thought would be necessary to have for the further classroom talk about sexuality. Sanna explained her use of this strategy:

> I think it is important to put into words, that we make sure we stay respectful in this topic. There is so much talking about personal and perhaps slightly vulnerable topics. So, it is completely clear that this is how we behave (Sanna, SRI2).

Sanna wanted students to be involved in designing rules for the classroom discussions about the sensitive topic of sexuality. This topic-specific discussion resulted in rules like 'We don't share personal experiences.'

Science-specific strategies are suitable across science topics. There was little evidence of science-specific strategies in the interviews (2% of the integrated segments). In one example, Lena reflected on the sequence of her instruction in technology and design. She started out with theory about electric circuits. Then students got a worksheet with different wiring diagrams and predicted if the bulb would light in each diagram. Finally, students tested their predictions with a battery, wires, and a bulb. She shared this reflection about the structure: ´I started out with theory and closed with the practical´ (SRI2). Lena saw this pattern as natural for various topics within science and used it to teach electricity in her technology and design lesson.

All PSTs used primarily topic-specific activities, representations, and discussions. The purposes of clarification, application, and student participation were often integrated with these strategies. The above examples show that instructional strategies were diverse and uniquely designed by the PSTs themselves. Rather than relying on PK, the participating beginner PSTs used their PCK to design their lessons and choose instructional strategies.

Assertion 4: The PSTs Referred Specialized Science Courses, Peer PSTs, Personal Learning Experiences, and Mentor Teachers as the Sources of their KSU, KIS, and Integration of Those

Table 8 shows the frequency of integrated segments with references to sources for each PST. Note that PSTs

Table 8. Integrated segments with references to sources of KIS, KSU, and integrations

Source	KSU	KIS	Integrated KSU—KIS	Sum KSU, KIS, and integrations
Specialized science courses	0% (0)	24% (9)	10.5% (4)	34.5% (13)
Peer PSTs	8% (3)	8% (3)	13% (5)	29% (11)
Personal learning experience	0% (0)	8% (3)	13% (5)	21% (8)
Mentor teacher	5% (2)	0% (0)	10.5% (4)	15.5% (6)
Total	13% (5)	40% (15)	47% (18)	100% (38)

Number is parenthesis refers to actual frequency.

referred to more than one source in some of the integrated segments.

Specialized science courses for PSTs at the university were the most frequently cited source for KSU, KIS, and integrations. Sexual health was taught in a specialized science course a short time before Lena's first field practicum. She used a puberty video shown in the specialized science course as an introduction to her lesson. ´We discussed this video, because it was included in the campus instruction, where some used that video´ (SRI1). She chose to use this video after first discussing its appropriateness with her PST peers. Jakob reflected on his instruction about renewable fuels and attributed the specialized science course as being highly influential. 'We have had many examples of what you can do (in science instruction) and much more knowledge about. Unlike math which I have not had any (courses in before teaching it in field practicum)' (SRI2). Jakob stated that specialized science courses were an important source for his own practice as a PST.

Peer PSTs was the second most frequently mentioned source. Jakob borrowed an instructional strategy designed by Lena for his instruction about renewable fuels. She wanted to illustrate that a time span of several thousand years is considered a relatively short time span in comparison to the millions of years it takes to form fossil fuels. Students were asked to put on their ´physics glasses´ by forming circles with their fingers and holding them up to the eyes.

> Lena has taken this up with them, with the physics glasses. And then I think we've used it here before with them. There is something they know, then I think then we can continue to use it as a concept of thought (Jakob, SRI2).

Jakob used Lena's successful strategy to help students think in a geological time scale. Peer PSTs were a frequently mentioned source for integrations of KSU and KIS. In Ingvild's lesson on sexual health, peer PSTs supported her by anticipating that students in the group would pose few anonymous questions about sexuality when asked (*KSU*). So, they agreed to write some questions as inspiration, making the instructional strategy of answering anonymous questions more effective in the specific group (*KIS*) (Ingvild, SRI2).

In eight integrated segments, PSTs referred to their own *personal learning experiences* as a source; these were experiences from their former schooling. Ingvild reflected upon her use of online videos in her nutrition lesson. She had experiences from school that videos in science instruction often had connected to elements in her own life as a child. This led to her use of videos in her own instruction. Therefore, personal learning experience was a source of KSU-KIS integration. In Sanna's instruction about energy content in food, she had students eat either a piece of potato chip or carrot and later burn the equivalent of the energy in the portion by jumping on their chairs. Her *personal learning experience* was the source of this instructional strategy.

> I remember it (the chip and carrot activity) from lower secondary school. That it was fun, and we realized the difference in that it is very much energy in a small amount of potato chips, and intermediate or little energy in a small carrot. Moreover, they got to feel on the body what energy in food is (Sanna, SRI1).

Here, Sanna shared how she made use of a topic-specific instructional activity from her experience as a student in lower secondary school to teach how foods vary in calories.

Mentor teachers were the final source identified by the PSTs. Each group of three PSTs was mentored by a teacher at their practicum school. Ingvild talked to the mentor teacher before her instruction about sexual health. She received information about how the students usually responded to talking about sexuality, which informed her use of a task where all students handed in anonymous questions

> The student group is quite mixed both with background from different cultures and it is not everyone who is equally open about this at home. Therefore, we also consulted with the mentor teacher, which had consulted with the mother tongue teacher (Ingvild, SRI2).

Ingvild's mentor teacher reminded her to consider cultural differences among the students, and thereby integrate KSU and KIS. Pia also consulted with her mentor teacher before teaching female puberty. The mentor teacher shared thoughts about the students' attitudes towards sensitive topics, and provided advice regarding whether the boys should participate in the instruction about tampons. The mentor teachers was identified as a minor source. They selected the topic to be taught, but allowed the PSTs to choose how they would teach the topic.

Specialized science courses, peer PSTs, personal learning experiences, and mentor teachers were sources for PSTs' KSU, KIS and integrations of those categories. However, instructional strategies were not implemented in an uncritical way. The PSTs' use of sources was characterized by acknowledging the uniqueness of the current context and reflection of each instructional strategy's appropriateness.

DISCUSSION

This study addresses a gap in the literature regarding teachers' enacted PCK and the nature of integration among the PCK components KSU and KIS. Research indicates that expert teachers integrate all five PCK components (Park & Chen, 2012; West, 2011), while novice teachers show less complex integration (Akin & Uzuntiryaki-Kondakci, 2018). Although the two components, knowledge of students' understanding and instructional strategies has been a focus in PCK research (Brown et al., 2013; Chan & Hume, 2019; van Driel et al., 2002); the specific nature of integration between these components remains unexplored. Building on Park and Chen's (2012) PCK mapping approach, we did a fine-grained analysis of six beginning PSTs' integrations of knowledge of students and instructional strategies based on reflections on their instruction. We took a comprehensive approach by looking at integration at the PK, science-PCK, and topic-specific PCK levels. We discuss the integration of knowledge of students with knowledge of instructional strategies, primarily topic-specific strategies; and the sources contributing to these integrations.

KSU was Integrated with KIS, Primarily Topic-Specific Strategies

Researchers have reported that beginning teachers lack integrated PCK for specific topics (Akin & Uzuntiryaki-Kondakci, 2018; Aydin et al., 2015; Brown et al., 2013; Sickel & Friedrichsen, 2018). The current study contributes to the literature by reporting a contrasting finding in that the six PSTs did show integration of these two PCK components at the topic level. Further, we add to the literature by unpacking the mechanisms of this PCK integration. We show empirical evidence of their frequent and complex integration between KSU and KIS in the realm of ePCK. The PSTs frequently identified students' prior knowledge and current science understandings. Across the material, we discovered PSTs' awareness of students' foundational knowledge suitable to build on, not just their misconceptions. This indicates progress in science teachers' PCK development (Schneider & Plasman, 2011). The PSTs used this knowledge and other elements of KSU to inform instructional decisions. Five of the lessons we studied were about sexual health. Timmerman (2009) showed that teachers typically emphasize students' conceptions during sex education, including for example knowledge about youth's lifestyle. Thus, the topic itself may have led PSTs in the current study to considering students more. However, Timmerman (2009) also showed that teachers may remain focused on the impersonal aspects of sexual health, such as the menstrual cycle and contraception. PSTs in our study chose to include and focus on aspects relevant for students such as the socio-emotional and relational aspects, strengthening their KSU – KIS integration. All PSTs in the study integrated these two PCK components, seen as important for effective teaching (Akin & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012). Friedrichsen et al. (2009) reported that beginning teachers who lacked a teacher education background did not develop PCK from teaching experience alone. Our finding of PCK integrations in the realm of ePCK aligns with and deepens insights from prior research indicating significant intra-relationships between knowledge of students and knowledge of instructional strategies for PSTs (Kaya, 2009) and identification of instructional strategies and student thinking as PCK components linked by PSTs (Schneider, 2015).

In regard to various forms of KSU, we add to current understanding of PSTs' attention to students in that Jens, Jakob, and Lena focused on students' difficulties, while Ingvild, Sanna, and Pia focused on student characteristics. We conjecture that when teachers focus on students' learning difficulties, this indicates an emphasis on the science content, while teachers focusing on student characteristics indicates their emphasis on students in general. Lidstone and Hollingsworth (1992) found that some teachers focused on classroom management and content knowledge, while other teachers focused on students. As Lidstone and Hollingsworth (1992) suggested, we also think that teachers who focus on students (e.g., Ingvild, Sanna and Pia) benefit from working with teachers focused on content (e.g., Jens, Jakob, and Lena). Within the field practicum groups, PSTs did this as they planned lessons together and discussed their instruction. Careful grouping of PSTs in field practica, as well as supportive mentoring, can broaden the PSTs' focus of attention.

This study contributes evidence of PSTs' use of topic-specific instructional strategies. Topic-specific representations, activities, and discussions dominated in the PSTs' instruction. These were strategies developed for teaching specific science topics, or general pedagogical strategies adapted or applied to the specific topic. For example, Jakob taught about pimples by making a representation with the essential components of the skin only. Jens initiated a topic-specific activity where students looked at their thumbs with one eye, discovering that the thumbnail seemed to disappear when in the blind spot. And Ingvild initiated a topic-specific discussion with the student groups on etiquette while discussing the sensitive topic of sexuality. The frequent topic-specific strategies contradicts earlier research indicating beginning teachers enact mostly general pedagogical strategies (Friedrichsen et al., 2009). Rather than implementing existing unit plans, the PSTs in the current study planned each lesson they taught, reasoning about the students' needs, what was important to cover in the topic, learning goals in the national science curriculum, and different instructional resources. When no suitable instructional strategy for teaching a specific topic was available, PSTs were creative and adapted existing general pedagogical strategies to the topic at hand, or invented new topic-specific instructional strategies. Because the PSTs were required to plan their own lesson, rather than rely on existing lesson plans, this may have contributed to their integration of KSU and KIS.

Although inquiry-based teaching is seen as important in science education (Crawford, 2014; Lederman & Lederman, 2019), it was largely absent from our material. One of few examples of experiments were enacted by Jakob in his lesson about energy and fuel. He demonstrated burning of washcloths made of different materials, after students suggested hypothesises on which cloth would burn more easily. However, the experiment was loosely connected to the topic of the lesson. This finding suggests that PSTs need strong support to teach science as inquiry.

The rationale for PSTs' instruction varied. Rationale is the inferred reason describing why the instructional strategy in a segment was used. Each PST integrated at least one topic-specific strategy with each of the following rationales: *clarification*, *application*, and *student participation*. This finding shows complexity of PCK integrations not described in the literature. It is evidence that PSTs not only used suitable instructional strategies to transform their content knowledge for teaching, but instructional strategies were used to serve a variety of goals in response to students' needs. For instance, Jakob used a topic-specific representation to apply the concept of emotional confusion during puberty to the students' lives.

Sources Contributing to Integration of KSU and KIS

The PSTs referred to specialized science content courses, peer PSTs, personal learning experiences, and mentor teachers as sources contributing to their KSU, KIS, and KSU-KIS integrations.

Most of the PSTs identified the specialized science courses as a source of KSU, KIS and integrations. Ingvild referred to specialized science courses as the source when using a topic-specific discussion to help students think about healthy food (Ingvild, SRI1). Jakob stated that participating in specialized science courses boosted his confidence for teaching. Compared to teaching mathematics, in which he had no university courses, he had higher confidence when teaching science. He explains that in science, 'We have had lots of examples of what to do and much more knowledge' (Jakob, SRI2). Integration of KSU and KIS was supported directly by specialized science courses. For example, Lena brought a heightened attention to issues of homophobia and ways to work with this in classes from a specialized science course (Lena, SRI1). Grossman (1990) pointed towards subject-specific teacher education as facilitating PCK development. Our findings show that specialized science courses were useful sources for PSTs in developing their PCK. Specialized science courses presented science content in a practical way, aiming to prepare teachers for school science teaching in topics relevant for primary and lower secondary school. Course instructors emphasized common misconceptions, and how to address them in a school setting. It seems likely that specialized science courses was a major cause to the PCK integrations we have identified. The relationship between specialized science courses and PSTs' PCK development should be a subject for further investigation.

Each PST worked closely with peers and a classroom mentor during field practica. Peer PSTs was the second most frequently mentioned source, while classroom mentors were occasionally referred. All PSTs discussed lesson plans and issues regarding instruction with peer PSTs and the classroom mentor, and they observed each other's instruction. In some lessons, peer PSTs helped each other during instruction. For example, when Sanna viewed video recordings of her explanations about kids with ambiguous sex, she came up with this reflection '[Here I am] looking at Ingvild. This was something we had discussed. To be sure it was right, I had to look at her' (Sanna, SRI2). Also, Sanna was inspired by her classroom mentor to build on the prior lesson, she stated '[When observing her instruction], she was good at that' (Sanna, SRI1). Our findings indicate the value of placing PSTs in groups for field practica, mentored by a classroom teacher. In the Refined Consensus Model of PCK (Carlson et al., 2019), collective PCK (cPCK) is represented as the realm of PCK outside of the specific learning context, e.g., the PCK available in a team of teachers. In the current study, PSTs referring to each other represents personal PCK (pPCK) developing from cPCK available in the group, which is a contribution of the study.

Experience as learners in school was a source for PSTs' KIS and integrated KSU and KIS. For instance, Jens reflected that he had always been a knowledgeable student who often explained concepts to others; he used this experience as a resource when using a topic-specific representation to clarify for the students why we see colours (Jens, SRI1). Ingvild used a topic-specific instructional strategy for teaching concepts in her lesson on nutrients, inspired by her high school biology teacher's lesson. Developing PCK from earlier experiences as 'apprenticeship of observation' is known to be a complex affair for PSTs (Juhler, 2017). Many years of observing instruction of specific content is a resource of instructional strategies for PSTs, but drawing upon this experience can also conserve teaching (Grossman, 1990). Interestingly, PSTs generally did not seem to adopt instructional strategies they had experienced as learners without first reflecting upon them from a teachers' point of view. Personal learning experiences also helped PSTs integrate KSU and KIS. For example, Sanna's experience with eating a piece of potato chips and later burning the equivalent of the energy in the portion by jumping on her chair in middle school inspired her acknowledging that students learn better by being active, and implemented the same activity in her own instruction (Sanna, SRI1). When inspired by her former high school biology teacher to use the picture-concept instructional strategy, Ingvild reasoned that students could 'make connections and get to talk about it, discuss the words. And I got the opportunity to see ... particular issues which several struggled with' (Ingvild, SRI1). This way, Ingvild used prior learning experience as a source of KSU-KIS integration. Rather than adopting practices uncritically, the PSTs seemed to select from their most productive learning experiences as they planned their lessons. This finding provides evidence that the PSTs were working to overcome the challenges of 'apprenticeship of observation'.

IMPLICATIONS

For Teacher Education

Our findings indicate that an early emphasis on knowledge of students' understandings in pedagogy courses and specialized science courses facilitates PCK integration. The PSTs participating in the current study had topic-specific PCK for the topics in the studied lessons, and they showed a reflective use of prior learning experiences. Therefore, PSTs should not be treated like blank slates to be filled with knowledge for teaching by teacher educators. In regard to additional sources of knowledge, PSTs should be encouraged to collaborate with each other, to draw upon and critically examine their emerging cPCK.

For Future Research

Our analysis introduces a new level of detail to the PCK maps designed by Park and Chen (2012). Through fine-grained analysis, we unpacked the details in instructional segments with regard to integration of knowledge of students' understanding and instructional strategies. Detailed PCK maps based on stimulated recall interviews can benefit PCK research by providing access to individual teachers' ePCK. There is need for a closer look at integration among the remaining PCK components. Further, the surprisingly positive findings from the current study of PSTs invites a detailed comparison of beginner and experienced teachers' PCK integration to understand the factors of effective teaching. Lastly, specialized content courses' impact on PSTs' development of integrated PCK should be a case for further investigation.

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APPENDIX

Supplemental Material A

In Table S1, we illustrate coding of an integrated segment from Jakob's instruction about male puberty**.** At the start of the video lesson transcript, Jakob reflected on how students approach talking about sex. Therefore, the integrated segment was coded to *science student characteristics (KSU).* As an illustration of how kids change attitude towards sex throughout puberty, Jakob chose to act as if he virtually 'moved' sex from the category of 'nasty words' in a kid's brain to the category of 'interesting words'. This was coded to *topic-specific representations (KIS)*. The representation was enacted in order to apply knowledge about pubertal change in the brain to the students' own lives. The integrated segment was therefore coded to *application (rationale)*.

Table S1. Coding of integrated segment

Integrated segment from Jakob, SRI1 Topic for instruction: Male puberty	Coding of the integrated segment
Video Lesson Transcript: Jakob: *Because right now, if I say "sex" for example, and all that, I see all, I see just Jenna (student) just "tchhh". You think I am a bit nasty, just. Love and everything like that is a bit disgusting. Like "No, no, no, let's not talk about that".* *And that is a little inconvenient if humanity is to carry on. Because it has to turn to something "mm, this was not that bad". And that is what happens inside the brain right now. One goes into the brain and take a big box like "yuck" and a box thinking "not so bad", and one take "hm, it has to go over in that one" (Jakob is acting as if he move something from an imagined "yuck" box to a "not so bad" box). So then much is rearranged. And this gets fixed with hormones.*	Category: *KSU,* subcode: *science student characteristics*
SRI Transcript: First author: *You use a model here, an illustration here now* (referring to another illustration). *Can you say something about what you thought there and then?* Jakob: (Answering about the moving of sex to another box.) *That one was not planned at all. It was in the very second that thought "I can do that"*	Category: *KIS,* subcode: *topic-specific representations*
First author: *What did you say?* Jakob: *It was not planned to take that way there you have a box and then it will be moved over. That was in the moment-planning. So it was. So, I have had quite a lot of such a church and devotionals there. And then it is a lot of comparison. So I feel I have quite good control of finding things similar to what I'm just talking about. Because that's a parable. Because you explain a parable of taking a new parable. So I feel I've got control of that.*	Category: *rationale,* subcode: *application*

Supplemental Material B

Table S2. Example of coding sources of instructional strategies

One of Ingvild's integrated segments, SRI2 Topic for instruction: Sexual orientation and gender identity	Coding: Sources
SRI Transcript: First author: Please tell me more about where you got inspiration for this lesson. Ingvild: There are really a lot from 'Week Sex' (curricular material used in their specialized science course). Both the rule activity and 'four corners,' coming after the break. That one is from grade 8-10 actually, but it is also mentioned for grade 5-7. I experienced the 'anonymous questions' activity in the science instruction, and it is mentioned in 'Oppdag naturen' First author: Yes, your textbook at the university? Ingvild: Yes, within biology.	*Source of KIS: Specialized science courses*

Paper 3: Classroom impact from specialized science courses

Sæleset, J., & Friedrichsen, P. (Under review). A case study of specialized science courses in teacher education and their impact on classroom teaching. *Journal of Science Teacher Education.*

Abstract

Specialized science courses (SSCs) integrate content knowledge (CK) with pedagogical content knowledge (PCK) and prepare pre-service teachers (PSTs) for reform-oriented teaching. Studies of individual SSCs report positive short-term outcomes, including an increase in self-efficacy and CK. However, few studies explore the longer-term impact of SSCs on classroom teaching. We carried out an exploratory case study of three PSTs from a Norwegian teacher education program that included SSCs. In the context of their field practicum, we compared PSTs' teaching of topics taught in SSCs (aligned lessons) with topics not taught in SSCs (unaligned lessons). Data collection consisted of field observations of one aligned and one unaligned lesson as well as stimulated recall interviews based on video recordings. In our analyses, we compared PSTs use of instructional strategies in aligned and unaligned lessons and how their knowledge for teaching informed these instructional decisions. We found that SSCs supported PSTs in using more topic-specific instructional strategies when teaching aligned lessons. In the aligned lessons, their teaching was better informed by knowledge of students' understandings in science. We also examined PSTs' perceptions of how they drew upon SSCs in their classroom teaching. They reported that SSCs had a major impact on their CK, PCK and self-efficacy for science teaching. Through this study, we provide unique insights into how PSTs draw on SSCs in their classroom teaching. We include implications for further research and the design of SSCs.

Keywords: Pedagogical content knowledge, instructional strategies, pre-service teachers, science education, specialized content courses, self-efficacy

Overcoming the gap between theory and practice is a major challenge for pre-service teachers (Allsopp et al., 2006; Grossman et al., 2009). The challenge is evident in the Nordic context (Rasmussen & Dorf, 2010), and for the subject of science (Thompson et al., 2013). In reform-oriented science teaching, teachers consider students and content rather than delivery of content only, and they implement inquiry teaching (Anderson et al., 1994; Sawada et al., 2002). One challenge for teacher educators is to develop pre-service teacher's (PSTs) theoretical and practical knowledge to prepare them to teach this way (Cochran-Smith & Villegas, 2016; McDonald et al., 2013). Another challenge occurs when PSTs attempt to introduce reform-oriented teaching practices in schools that may not be familiar with such practices (Crawford, 2007; Thompson et al., 2013).

To address these challenges, researchers and policymakers call for teacher education programs to shift toward a focus on teaching practices rather than theoretical knowledge about teaching (Blue Ribbon Panel, 2010; Darling-Hammond et al., 2017; Jenset, 2018). This movement provides a rationale for the inclusion of specialized science courses (SSCs) in teacher education programs. SSCs are science content courses, designed specifically for PSTs, in which instructors model reform-oriented teaching of science topics aligned with the grade levels that PSTs will teach. PSTs learn science content while also engaging in pedagogical discussions. These courses are built on the assumption that teachers tend to teach in the ways that they have been taught (Cochran-Smith & Villegas, 2016).

Teacher education programs can be an important starting point for developing science teachers' pedagogical content knowledge (PCK) (Friedrichsen et al., 2009). However, we have scarce evidence about the effects of teacher education coursework on developing reform-oriented teaching practices (Jenset, 2018; Stroupe & Gotwals, 2018). SSCs aim to support PSTs' development of PCK for reform-oriented science teaching. Many Nordic science teacher education programs for primary and middle school levels include SSCs. These programs focus on the development of teaching experts rather than content experts (Rasmussen & Dorf, 2010). However, separate science content and methods courses tend to be the international norm (Etkina, 2010; Fones et al., 1999). In this study, we addressed a gap in the literature on whether and how PSTs use what they have learned in their teacher education program (Cochran-Smith & Villegas, 2016; Jenset, 2018), specifically the influence of SSCs on PSTs' practice. We carried out an exploratory case study of three PSTs from a Norwegian teacher education program that included SSCs. The study takes place within a subsequent field practica in a local school. We contrasted the PSTs' teaching of topics that were taught in prior SSCs (aligned lessons) with topics not taught in their SSCs (unaligned lessons). Moon phases and seasons are an example of an aligned lesson; the PSTs learned about moon phases in a SSC and later taught this topic in their school practicum. An unaligned lesson is a lesson taught by the PST (e.g., animal cells and oxygenation); however, the PST had not learned the topic in a SSC. Specifically, we aimed to explore two questions: (1) In three Norwegian science PSTs' practica in lower secondary school (ages 10-16), what were the differences, if any, between lessons aligned and unaligned with specialized science courses? (2) What were these PSTs' perceptions of how they drew upon specialized science courses?

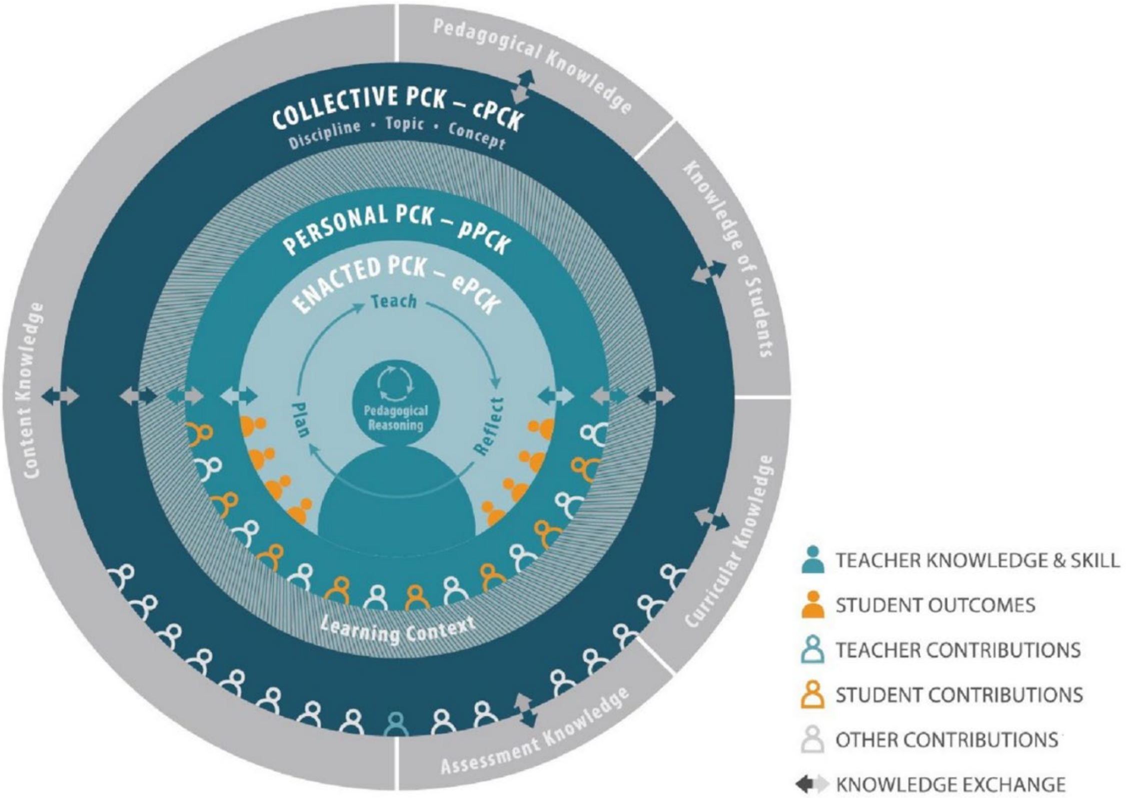
Theoretical framework

Shulman (1986) proposed pedagogical content knowledge (PCK) as an important part of a teacher's knowledge base. Teachers have specialized knowledge for teaching specific topics to specific students (Shulman, 1986). In the current study, PCK serves as the theoretical framework as we are examining PSTs' specialized knowledge for teaching specific science topics. Some PCK researchers view PCK as topic-specific knowledge for teaching (e.g., how to teach a specific topic such as photosynthesis) (Gess-Newsome, 2015; Mavhunga, 2020), while others view PCK as specialized knowledge at the discipline level (e.g., how to teach argumentation in science courses) (Davis & Krajcik, 2005). In this study, we examine both topic-specific and science-specific PCK. Magnusson et al. (1999) conceptualized topic-specific PCK as consisting of four components comprised of knowledge of science curricula, students' understanding in science, instructional strategies, and assessment of scientific literacy. To examine science-specific PCK, we use the same Magnusson categories (Friedrichsen et al., 2009).

The most recent PCK model in science education (Fig. 1) distinguishes between three realms of PCK: enacted PCK, personal PCK, and collective PCK (Carlson et al., 2020).

Figure 1

The Refined Consensus Model of PCK



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Each realm refers to the context in which PCK is manifested: in the classroom during enactment, in the individual teacher's knowledge base, and collective knowledge held among colleagues or published in the field. The model weaves together knowledge (personal and collective PCK) and skills (enacted PCK) for science teaching. In this study, we researched personal and enacted PCK as we conducted stimulated recall interviews and related this to collective PCK from SSCs. High quality PCK is characterized by integration of PCK components (Abell, 2008; Chan & Hume, 2019). Integration between knowledge of students' understanding of science and knowledge of instructional strategies is a critical step in developing highly integrated PCK (Akin & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012). In the current paper, this integration is studied in the realm of enacted PCK.

Literature review

SSCs are university courses designed specifically for education majors to support the development of science content knowledge (CK) and PCK. The main goal of the courses is to develop CK, while PCK is addressed through course instructors' modeling of reform-oriented instructional practices, and by explicitly focusing on K-12 students' common misconceptions related to the topic. In contrast, science teacher education programs are often based on content courses characterized by lectures in a science discipline, lab sessions, and separate science methods courses (Etkina, 2010; Fones et al., 1999). Such programs, though cost-effective, often provide PSTs with poorly taught CK of limited relevance for their future career and limited PCK for specific topics (Bergman & Morphew, 2015; Fones et al., 1999). Grossman et al. (2009) called for teacher education to undo divisions between university and K-12 schools. One should not assume that learning about teaching practices through reading articles or writing papers is enough to prepare PSTs for classroom teaching, particularly student-centered or reform-oriented teaching (Horn & Campbell, 2015; Sun & van Es, 2015). In line with this, SSCs integrate CK and PCK in some of the following ways:

- using a constructivist epistemology, requiring that learners are active in the knowledge-building process (McLoughlin & Dana, 1999).
- being student-centered by engaging PSTs in their own learning process and connecting the course to science classroom teaching at relevant levels (Etkina, 2015).
- implicitly learning about instructional strategies, such as through implementing scientific practices like inquiry (Bergman & Morphew, 2015; Cochran-Smith & Villegas, 2016; Knaggs & Sondergeld, 2015).
- explicitly presenting instructional strategies and addressing issues regarding different approaches to teaching (McLoughlin & Dana, 1999).
- using a variety of ways, building on the premise that teachers tend to teach in the same way in which they learned the content. (Avard, 2009; Bergman & Morphew, 2015; Cochran-Smith & Villegas, 2016).

Case studies of courses or programs using pre/post-tests of content knowledge, beliefs, or teaching practices were often used in evaluating SSC outcomes. One outcome of SSCs was an increase in PSTs' content knowledge. Studies of specialized physics courses (Etkina, 2010; Menon & Sadler, 2016) and a specialized astronomy course (Bell & Trundle, 2008) reported an increase in content knowledge test scores at the end of the courses. Additionally, PSTs have highlighted group work and discussion in specialized physics courses as helpful in their concept learning (Doster et al., 1997). PSTs with more prior knowledge in the topic were most comfortable with the reformed teaching model used in the SSC (Doster et al., 1997).

A second outcome is that reform-oriented learning in SSCs supported the development of PSTs' knowledge of and approaches to teaching science. Cochran-Smith and Villegas (2016) reported how PSTs adopted constructivist views of teaching and learning through experiences like problem-based learning, role playing, analyzing video cases, and performing collaborative research. Similarly, Varelas et al. (2008) reported on four SSCs for elementary PSTs characterized by a focus on student understanding and a balance between attention to key concepts and science as inquiry. Participating PSTs noticed how constructivist instructional tools (i.e., concept maps, group work and projects) facilitated meaning and connection making. Although the main goal of the courses was CK learning, PSTs noticed curricular, instructional and assessment features and made connections to future classroom practice. Only one longitudinal study traced PSTs' knowledge and practices from SSCs into classrooms. Etkina (2010) evaluated a physics teacher education program featuring interactive-engagement pedagogy and frequent opportunities to practice instruction. Using an observation protocol (RTOP) over three years, she found the program supported PSTs in enacting reformed teaching practices in school practica.

A third outcome of SSCs was the development of self-efficacy for science teaching. Research has documented critical links between self-efficacy beliefs and teaching practices (Menon & Sadler, 2016). Several studies utilized the Science Teaching Efficacy Belief Instrument (STEBI-B) (Enochs & Riggs, 1990) as pre/post-tests of PSTs' self-efficacy. The studies reported gains in self-efficacy for teaching science from specialized courses in physics (Menon & Sadler, 2016), geoscience (Posnanski, 2007), and an integrated science course (Knaggs & Sondergeld, 2015). These gains in self-efficacy were attributed to implementation of constructivist instructional methods in the SSCs (Posnanski, 2007), such as using activity-based curriculum, pedagogically oriented assignments, and having opportunities to collaborate with both instructors and peers (McLoughlin & Dana, 1999). All of the studies reviewed above report PSTs' self-efficacy gains at the completion of the SCCs; there were no longitudinal studies that studied PSTs' self-efficacy as they taught in classrooms.

Need for follow-up classroom research of PSTs' practice

Jenset (2018) reported overall thin evidence of the effects of teacher education coursework due to the lack of longitudinal research on actual teaching practice. We identified only one study (Etkina, 2010) evaluating the influence of SSCs on PSTs' teaching practice in actual classrooms. However, this study looked at teaching practices at a general level and did not compare classroom lessons to topics taught in the SSCs, and PSTs were not interviewed to capture a nuanced picture of the impact from the SSCs. By studying the impact of SSCs on classroom teaching in a field practicum setting, the current study addresses these gaps. The current study also is a response to calls for research on what aspects of science teacher preparation matter in terms of PSTs' perspectives and teaching practices (Wilson et al., 2001; Zeichner, 2010).

Context

The current study was undertaken in a Norwegian five-year teacher education program for primary and lower secondary school teachers (grade 5-10, ages 10-16). At the end of the program, PSTs earned an undergraduate and master's degree. In each year of the program, PSTs enrolled in specialized content courses for teachers in three subjects of choice. PSTs chose one subject as their main subject. The program align with the Nordic teacher education model due to its focus on teaching methods rather advanced CK in the subject. PSTs do not earn a degree in a subject, but they complete a 45 ECTS master thesis in teaching methods for the subject (European Credit Transfer and Accumulation System, 60 ECTS is equivalent to one-year full-time study). Alongside with their specialized content courses, the PSTs completed courses in Pedagogy and Student Knowledge as well as Research and Development in Education. These courses covered general pedagogical knowledge, additional teaching methods, and educational research. Each year included six weeks of mentored field practicum, approximately three weeks of full school days in each of the fall and spring semesters. Some of the PSTs' lessons would be on topics in which the PSTs had received instruction in the SSCs (aligned lessons), and some which they had not (unaligned lessons). In the aligned lessons, topics aligned with main topics taught in SSCs. This study focus on the contrast between aligned and unaligned lessons.

Participants

Jakob, Pia, and Tina (pseudonyms) were PSTs with an emphasis on science and they agreed to participate in the study. They were assigned to two mentor teachers at the same lower secondary school (grade 8-10), and they were able to teach at least one unaligned and one aligned lesson. Another two PSTs mentored by the same mentor teachers were not able to teach two such contrasting lessons and were omitted from the study. Table 1 shows the characteristics of Jakob, Pia, and Tina and the unaligned and aligned lessons in this study.

Table 1

Participants and their science lessons

PST	Jakob	Pia	Tina
Age	20	25	30
Science specialization from high school	Biology, two years	None	Biology, two years
Teaching-related experience	Leader of leisure activities for 5-17-year-old kids	Substitute teacher, immigrant language training	Parenting
Unaligned lesson	Alcohols	Animal cells	Animal cells and oxygenation
Focus	Alcohols as a group of hydrocarbons, solubility in water, flame color	Comparison of plant- and animal cell structure, metabolism, forms of animal cells	Structure of cells, structure of lungs, diffusion of oxygen, distribution of oxygen
Instructional strategies	Lecture with use of molecule model, discussions and tasks in whole-class and pairs, burning of alcohols at the lab, quick posters from the lab	Whole-class discussion, individual drawing, textbook tasks, lecture with use of illustrations, video, matching of concepts with definitions	Discussions in whole-class and pairs, videos, lecture, individual textbook tasks
PSTs’ preparation	Self-studied hydrocarbon using multiple resources	Self-studied the topic using multiple resources	Self-studied the topic using multiple resources. Experience from teaching about human lungs

			and heart from first-year school practicum
Aligned lesson	Oil	The stars, the sun, and northern lights	Seasons and moon phases
Focus	Fractions of oil, products based on oil	The sun as a star, distance to stars, surface of the sun in relation to northern lights	Cause of moon phases, seasons, solar- and lunar eclipses
Instructional strategies	Lecture with use of illustrations, distillation of crude oil at the lab, discussions in groups and whole-class	Discussion in whole-class and pairs, lecture with use of illustrations, videos, thought experiment, and textbook tasks	Discussions in whole-class and pairs, lecture with physical model of seasons, practical activity with physical model of lunar phases
How SSCs were relevant to aligned lesson	Petroleum was recently taught in a SSC lesson. The SSC instructor demonstrated the distillation experiment. SSCs did not focus on oil-based products.	SSC included lectures on the sun, life of stars, and northern lights; activities about distances in the solar system, source of northern lights, models of the solar system, and an assignment where PSTs made a northern light forecast.	SSC included lectures on the sun, activities about distances in the solar system, and models of the solar system.

Note. Each lesson was 60 minutes long

Practica contexts: Mentor teachers

Prior to school practica in the third year of the program, two mentor teachers were recruited for the current study. These were invited because they each had 20+ years of teaching experience, more than five years of experience mentoring PSTs, were enthusiastic about school science, and agreed to facilitate opportunities for the PSTs to teach science during their practicum. The mentor teachers were asked by the first author to organize school practica so that every PST in their group would teach at least two 60-minute science lessons; one aligned lesson and one unaligned lesson. Pia and Tina taught a grade 8 class with 25 students, while Jakob taught a grade 10 class with 21 students. Within the groups, the PSTs cooperated in planning the lessons. The PSTs viewed the school culture as focused on following the textbook in the same pace as parallel classes, rather than providing student-centered and reform-oriented instruction. Pia and Tina were mentored by a male biologist with additional teacher education. He was not involved in the PSTs' lesson planning. After the PSTs taught lessons, he gave feedback on CK rather than pedagogy. Jakob's mentor teacher was educated as science teachers and gave specific teaching recommendations for his lesson plans, including the experiments to include.

Methods

This is an exploratory case study (Yin, 2014) of three PSTs who completed SSCs prior to their teaching practicum. This qualitative design was appropriate, as one purpose of the study was to identify themes for further investigation of classroom impact from SSCs. The study also has characteristics of a descriptive case study as we describe the impact from SSCs in the real-world context of classroom teaching (Yin, 2014). The case focuses on comparing a PST's lesson that was aligned with the topics in the SSC to a lesson that was not aligned. The cases are bounded by the three PSTs teaching of aligned and unaligned science lessons.

Data collection

Stimulated recall interviews

The main data source was stimulated recall interviews (SRI). SRIs are suitable to reveal both reflection-in-action and reflection-on-action (Meade & McMeniman, 1992). Through the use of SRIs, we were able to gain insights into the PSTs' rationale for their teaching practice (Gess-Newsome, 2015; Henderson & Tallman, 2006). The first author observed the entire 60-minute lesson and took field notes as a secondary data source. SRIs were conducted within a few hours after the lesson, in one case the following day. Pia and Tina were interviewed after two aligned lessons. In these cases, we selected one of the two, the one with clearest topical alignment with a prior SSC lesson. In the SRIs, the first author displayed segments of video from the lesson to the PST. Based on researcher's field notes, video segments including the most significant instructional strategies enacted in the lesson were selected. Due to time constraints, not every strategy enacted in the lessons was viewed, strategies for classroom management and communication with individual students were not viewed. Based on the video, the PSTs were prompted to share thoughts from planning and enactment of the instructional strategy. Follow-up questions from the researcher included, "Why did you do this?" and "From where did you get knowledge of such instruction?" A few general questions concluded the first of the two SRIs, e.g., *"*How has your knowledge for science teaching changed throughout the teacher education program*?"* Each interview lasted 45-55 minutes. SRIs were transcribed using QSR International's NVivo 12 Pro software (2019). The interviews, along with the corresponding audio of the video-recordings of the lesson, were transcribed.

Lesson plans

The PSTs' lesson plans included descriptions of the instructional strategies planned for the lesson, and the PST's short rationales for each strategy. Lesson plans were collected to get an overview of the lesson structure and triangulate PSTs' reflections shared in the SRIs.

Video recordings

The first author recorded the classroom teaching with a video camera and a microphone carried by the PST. The camera overviewed the classroom, facing the PST. Before recording in classrooms, we considered ethical aspects. All recorded persons provided informed consent to participate. The study was conducted with approval from the Norwegian Centre for Research Data, project number 54397. The lesson plans and video recordings were secondary data sources and served to triangulate the data.

Analysis

In the following, we explain the steps in analysis of the lesson plans, SRI transcripts, and video recordings. With this analysis, we aimed to answer the first research question describing any differences between aligned and unaligned lessons. First, SRI transcripts were divided into instructional segments. Every instructional segment was defined by enactment of a new instructional strategy, which was also discussed in the SRI. For example, one segment included initiation of a specific whole-class discussion about the cause of the seasons, while a second segment consisted of an explanation of a specific feature of the model of the sun, earth and moon. The segmentation facilitated a focused analysis of significant parts of the PSTs' pedagogical reasoning. Next, data from lesson plans and video recordings related to a specific instructional segment were added to the instructional segment data. For example, from the lesson plan, an additional rationale for an enacted instructional strategy was added to a specific instructional segment in the SRI transcript.

Second, we classified the enacted strategies as *topic-specific, science-specific* or *general pedagogical strategies* using protocol coding (Miles et al., 2014). In the protocol coding we used the subcodes *topic-specific activities* and *topic-specific representations* from the Magnusson PCK model (Magnusson et al., 1999). Table 2 shows the codes with definitions and examples of coding.

Table 2

Codes for classification of instructional strategies

Codes	Definitions	Examples
Topic-specific strategies	Developed and/or adopted for a specific science topic	
Topic-specific representations	Illustrations, examples, models and analogies about specific science topics	Presenting a model to explain the process of distillation
Topic-specific activities	Tasks, demonstrations, simulations, inquiries and experiments about specific science topics	Students are engaged in distilling crude oil in the laboratory
Topic-specific discussions	Discussions of topic-specific issues	Whole-class discussion on what components of plant cells are also found in animal cells
Science-specific strategies	Suitable across science topics	Students are assigned to write a standard lab report from an experiment
General pedagogical strategies	Suitable across school subjects	Students match concepts with correct definitions

Third, we coded PSTs' rationales for enacting instructional strategies. Rationale is defined as the reasons PSTs gave for enacting an instructional strategy. PSTs usually provided multiple rationales for enacting a single instructional strategy. We used provisional coding (Miles et al., 2014) based on a starting list of assumed rationales, to which we added emerging rationales. Rationales for PSTs' enactment of instructional strategies were grouped in topic-specific PCK rationales, science-specific PCK rationales, and general PK rationales. Table 3 shows the rationales with definitions and examples. The codebook was revised, and the material was re-coded several times until 100% agreement was reached between the authors.

Table 3

Codes for rationales, the reasons PSTs gave for enacting an instructional strategy

Rationales	Definitions	Examples
Topic-specific PCK rationales		
Build on prior knowledge	Activate students' prior knowledge and connect it to the topic at hand	Using a whole-class discussion to help students transfer what they know about plant cells to animal cells
Focus on key aspects	Ensure students understand important concepts and phenomena	Explaining moon phases because it is a central concept in the lesson
Address misconceptions	Instruction targeted to address known misconceptions	Directing a classroom discussion to address a misconception about the sun not being a star
Science-specific PCK rationales		
Use models	Student get experience with physical models or conceptual representations of scientific phenomena	To represent seasons, a physical model of the sun, earth and moon is presented in the classroom
Engage in inquiry	Students interpret data/observations to answer science-related questions	Students investigating how moon phases occur using a flashlight and a white ball in a darkened room
General PK rationales		
Engage students	Students participate in the lesson	Students discussing in pairs why some stars appear to be brighter than others, giving everyone the opportunity to formulate an answer
Variation	Change in instructional strategy to avoid boring students	Burning of alcohols at the lab to contrast the previous

		lesson which was heavy on theory
Use technology	Technology is used to make science content more interesting	Students matching concepts and definitions at the interactive board
Follow curriculum or mentor teacher	An instructional strategy is motivated by suggestions from curricular material or mentor teacher	Based on mentor teacher suggestion, students are writing a lab report as homework

Fourth, sources of PCK and PCK integrations were analyzed using causation coding (Miles et al., 2014). PCK integration refers to teachers simultaneously drawing on multiple components of PCK in planning and enactment of instruction. We focused on integration of knowledge of students' understanding of science and knowledge of instructional strategies. This is the most central and frequently occurring PCK integration, critical to teacher knowledge development (Akin & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012; van Driel et al., 2014). In this analysis, we used causation coding (Miles et al., 2014), as we extracted not just what happened, but which sources caused the PSTs to enact instructional strategies the way they did. For example, in her aligned lesson Tina engaged students in an activity where they used a flashlight and a white ball in a darkened room to demonstrate moon phases. In the following SRI, she referred to experience with this instructional strategy in a SSC lesson as the source for her use of it. When in doubt about the analysis, we contacted the PST and asked for elaborated responses on the specific issue. Later, we did a member check where participating PSTs commented on interpretations in this manuscript. Overall, the PSTs agreed with the findings.

To answer the second research question about the PSTs’ perceptions of how they drew upon SSCs experiences in their instruction, we analyzed responses to the general question concluding the first SRI and other relevant PST statements. We did a cross-case analysis to identify themes representing how PSTs benefited from SSCs in their classroom teaching.

Codes were defined inductively from reading the transcripts (e.g., the participants stated their self-efficacy for science teaching increased through SSCs) and deductively from the PCK components (Magnusson et al., 1999). *Self-efficacy for science teaching* was included in the codes as PSTs talked about how SSCs facilitated this, while *knowledge of topic-specific instructional strategies* was one of the codes from literature. With the cross-case analysis, we identified themes of SSCs' impact on classroom teaching across the cases.

Results

RQ1: In three Norwegian science PSTs' practica in lower secondary school, what were the differences, if any, between lessons aligned and unaligned with specialized science courses?

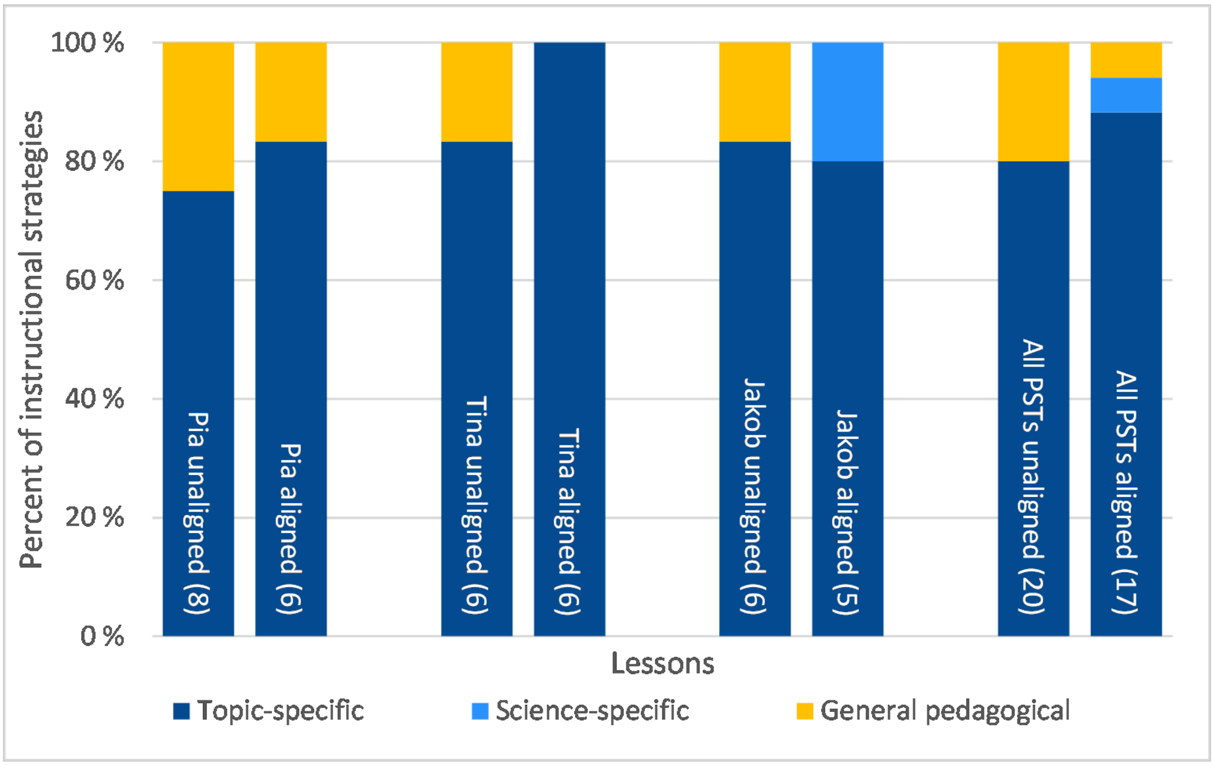
We present three assertions across the cases, with reference to data from the three PSTs' lessons.

Assertion 1: In the aligned lessons, PSTs enacted more science- and topic-specific strategies.

When comparing unaligned and aligned lessons, we found that science-specific and topic-specific strategies were enacted more often in the aligned lessons (Fig. 2).

Figure 2

Instructional strategies in percentages of strategies reviewed in SRIs.



Note. Number of strategies in parentheses.

In a majority of the instructional segments, especially in aligned lessons, PSTs drew on their PCK to enact science- or topic-specific strategies. Ninety-four percent (16 of 17) of instructional strategies in aligned lessons were science- or topic-specific strategies, compared to 80% (16 of 20) of strategies in unaligned lessons. Differences among individual PSTs were small. Pia and Tina enacted more topic-specific strategies and Jakob enacted more science-specific strategies in the aligned lessons. In Tina's aligned lesson on moon phases and seasons, all strategies in the instructional segments were topic-specific. She introduced the lesson with a topic-specific whole class discussion on the causes of seasons on earth. She used a Tellurium, a physical model of the sun, earth and moon, to explain seasons. She also used another topic-specific representation, a video explaining how moon phases occur. Later, students were engaged in a topic-specific activity as they used a flashlight and a white ball in a darkened room to demonstrate moon phases. In Pia's aligned astronomy lesson, she enacted a topic-specific discussion about why some stars appear to be brighter than others. In his aligned lesson on oil, Jakob had students do an experiment with distillation of crude oil, which is a topic-specific activity. Afterwards, he had students write a formal lab report as homework which is a science-specific strategy.

General pedagogical strategies were used slightly more often in unaligned lessons, four times in unaligned lessons compared to once in aligned lessons. One example was Pia assigning students to do textbook tasks such as answering the key questions at the end of the textbook chapter. In Jakob's unaligned lesson on alcohols, he had students make posters summarizing the flame-color experiment, which is a general pedagogical strategy, suitable across subjects.

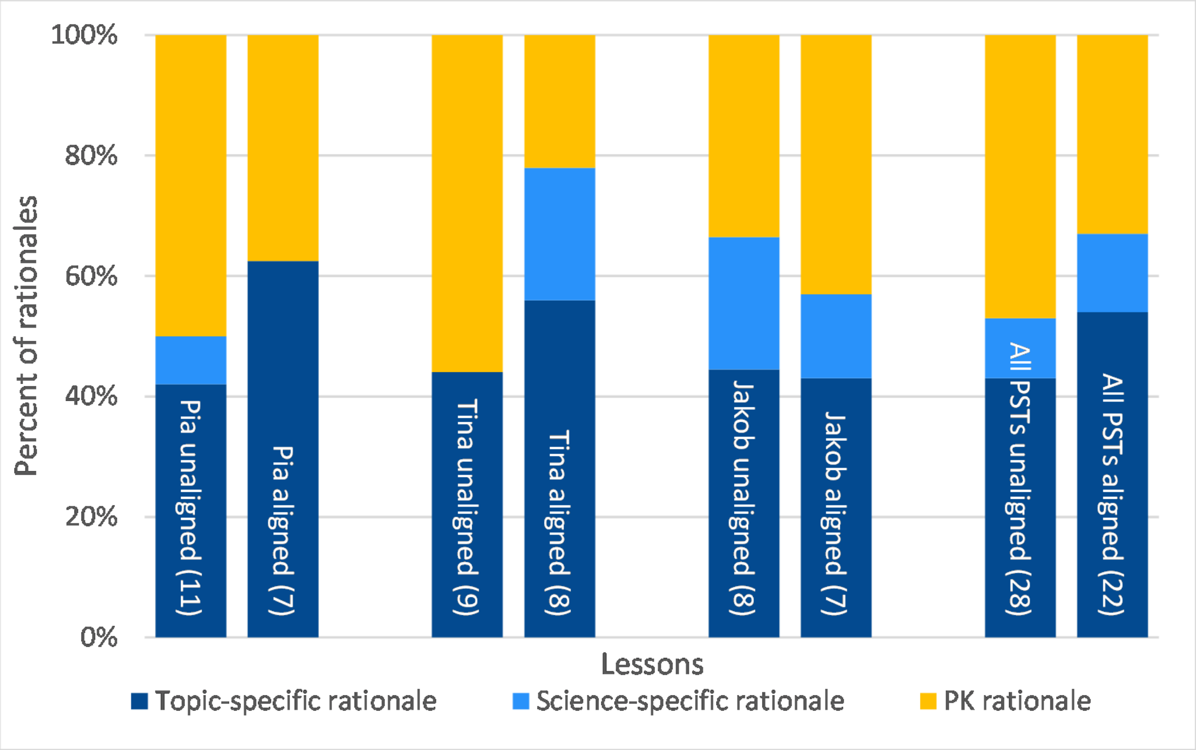
Assertion 2: In the aligned lessons, the PSTs used more topic- and science-specific PCK rationales for their instructional decisions.

In their lesson plans and during the SRIs, the PSTs provided rationales for the instructional strategies they enacted in their lessons. In the aligned lessons, the rationales were more often grounded in PCK (Fig 3). Three groups of rationales emerged: topic-specific PCK rationales, science-specific PCK rationales, and PK rationales. Topic-specific PCK rationales included PSTs enacting instructional strategies to build on students' prior science knowledge, focusing on key aspects of the topic, or addressing misconceptions. For example, in Tina's rationale for using a Tellurium in her aligned lesson, she emphasized she wanted to address the misconception of seasons being caused by earth's distance from the sun. Science-specific PCK rationales included PSTs enacting instructional strategies to use scientific models or to engage students in inquiry. For example, in her aligned lesson, Tina emphasized the importance of students getting to experience the phenomena of moon phases in her rationale for using an activity with flashlights and white balls. PK rationales included PSTs enacting instructional strategies to engage students, add variation to the instruction, make use of technology, or to follow the curriculum or mentor teacher's advice. An example of a PK rationale was found in Pia's reasoning for her use of a topic-specific activity in her unaligned lesson where students drew an animal cell and put names on the components. Pia emphasized the usefulness of every student having to think through what they had learned about the animal cell by drawing and labelling, and thereby engaging all the students.

Topic-specific rationales were described in the greatest frequency, and increased from 43% of rationales in unaligned lessons to 54% of rationales in aligned lessons. Within the topic-specific rationales, focusing on key aspects and addressing misconceptions increased the most from unaligned to aligned lessons. As PSTs were more aware of the key aspects and misconceptions in the topics which was taught in SSCs, they designed their aligned lessons to address those key aspects and challenge misconceptions. For example, in her aligned lesson, Tina used a video to address a common misconception that we have a full moon when the moon is on the other side of earth. The PSTs' focus on misconceptions indicate that their instructional decisions were more firmly grounded in PCK (i.e., knowledge of common misconceptions in a topic and knowledge of topic-specific instructional strategies) in the lessons when the topic was previously taught in a SSC.

Figure 3

Rationales for enacting instructional strategies in percentages of strategies reviewed in SRIs.



Note. Number of rationales in parentheses.

Differences were noted among the PSTs; Pia and Tina showed a greater percentage of PCK rationales in their aligned lessons in comparison to their unaligned lessons. For example, Pia emphasized variation as a PK rationale for using a video on metabolism in plants and animals in her unaligned lesson; she stated: “You got things explained in a different way …. variation pretty much.” In her aligned lesson on astronomy, she used another video about distances in space. This time, she emphasized, “It is important to understand distances in space” as a topic-specific PCK rationale for using the specific video.

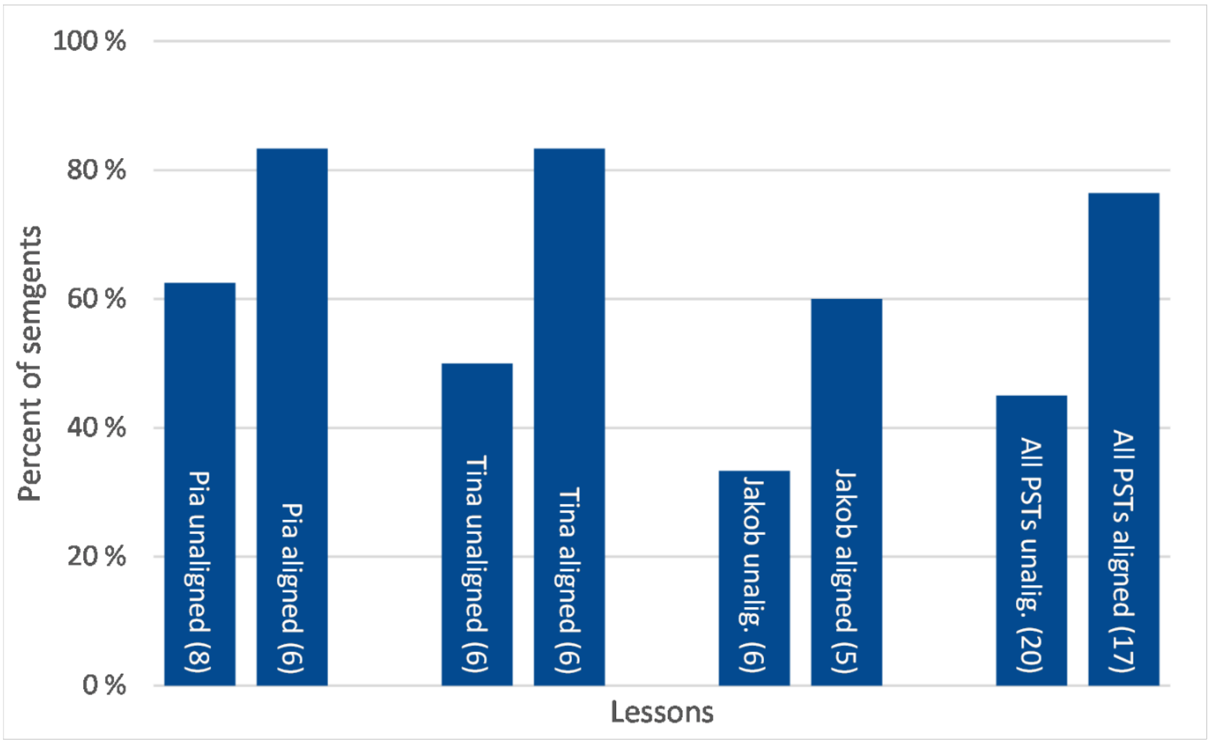
Jakob’s teaching showed the opposite development. He had a slightly higher use of PK rationales in his aligned lesson. This indicates that lessons aligned with SSC topics made a greater difference for Pia and Tina’s instruction than for Jakob’s. Although, the difference could be attributed to the restrictions set by Jakob’s mentor teacher. In his aligned lesson on oil, he had students distill crude oil. He explained his choice of strategy, “The experiment was scheduled. We were to do a distillation. I managed to fight through this that we did this with real oil.” The primary reason he enacted this topic-specific activity was the curriculum and the mentor teacher’s directive (PK rationale). Although, he modified the investigation by borrowing crude oil from the SSC instructor at the university instead of distilling Coke as described in the curriculum (Topic-specific rationale).

Assertion 3: Instructional strategies in the aligned lessons were more often informed by knowledge of students’ understanding of the topic.

In SRIs and lesson plans, we identified the instructional segments that included integration of knowledge of students’ understanding of science and knowledge of instructional strategies, two central components of PCK (Park & Chen, 2012). Such integration occurred more often in aligned lessons, as PSTs’ knowledge of students was more likely to inform their instruction. In contrast, instructional strategies in unaligned lessons were less often informed by PSTs’ knowledge of students’ understanding of the specific topic (Fig 4).

Figure 4

Knowledge of students informed instruction, in percentages of instructional segments.



Note. Number of segments in parentheses.

For example, topic-specific activities were more often informed by knowledge of students in aligned compared to unaligned lessons. Both Pia and Tina asked their students to draw representations of the topic but differed in their use of knowledge of students' understanding of science. In Pia's unaligned lesson she did not ground the task of drawing an animal cell in her knowledge of students' understanding of animal cells. In Tina's aligned lesson, the task of drawing an illustration of seasons on earth was clearly informed by her knowledge of students' understanding of space. She knew that students' drawings would have the potential to expose students' disregard of the earth's tilt as the explanation of seasons. In aligned lessons, topic-specific representations were also more often informed by knowledge of students' understanding of the topic. Jakob introduced both his unaligned and aligned lessons with lectures. In the unaligned lesson about alcohols, he lectured on alcohols as a functional group on hydrocarbon chains. This choice was made without referring to his students' prior knowledge, and the segment did not include integration of knowledge of students' understanding of science and knowledge of instructional strategies. In contrast, such integration was evident in the first segment in his aligned lesson, where the opening lecture was grounded in students' prior knowledge of the topic. He designed the lecture to build on students' prior knowledge of oil, and he addressed a misconception about distillation towers becoming cooler towards the top.

For Pia and Tina, we also see the contrasting integration at the lesson level. During planning of their unaligned lessons about animal cells and oxygenation, they drew on prior knowledge from high school biology, practitioner literature, and the student textbook. Although this led to reasonable structuring of the lessons, the PSTs had limited support for planning student-centered instruction. In contrast, Pia's and Tina's aligned lessons on astronomy were based on their knowledge of students' understanding of the topic. Their decisions were grounded in knowledge of what aspects of the topic were central, though difficult to understand for students, and common misconceptions held by students. Much of this knowledge was drawn from SSC lectures and course readings. We did not see a contrast on the lesson level of Jakob's lessons. Both his unaligned and aligned lessons were built around laboratory experiments scheduled by the mentor teacher.

RQ2: What were these PSTs' perceptions of how they drew upon specialized science courses?

The PSTs highlighted SSCs as an important influence in developing their knowledge and skills for teaching science. First, this was visible in PSTs' references to sources when reflecting on instructional segments in the SRIs. Fifteen of a total of 26 references to instructional strategies, knowledge of students, and integrations of these PCK components were related back to the PSTs' SSC experiences. Topic-specific instructional strategies, in particular, were drawn from SSCs. In the SRIs, there were ten occurrences where PSTs referred to SSCs as a source of topic-specific instructional strategies or integrations of such strategies with knowledge of students. The other sources were mentioned only two or three times each: student textbook, mentor teacher, peer PSTs, university courses other than SSCs, and personal learning experiences. Second, when looking at PSTs' responses to the general SRI questions related to the development of their science teaching knowledge, we found that SSCs were valued as sources of relevant CK, PCK, and self-efficacy in teaching science. Within PCK, the components most frequently discussed were knowledge of students' understanding of science, topic-specific instructional strategies, and science-specific instructional strategies. In the following sections, we give more detail on each of these aspects.

Relevant CK

The PSTs drew on CK from SSCs in their aligned lessons. For example, Tina learned about moon phases in a SSC astronomy lesson two years earlier, when she took part in a demonstration of the phenomena. In Tina's perception, CK learning through engagement in practical strategies enhanced her science CK. Pia also discussed ways that SSCs increased her learning of science CK. She expressed that the most useful lessons in SSCs were limited to the content level of the students they were learning to teach (age 10-16), and not focused on "knowing very much advanced physics and chemistry which I think we have focused a lot on but which I, at least until now, have had no use for." Through the first three years in the teacher education program, she had not seen the value of learning CK beyond what her future students were to learn. For example, the topic of stars' lives was taught in a first year SSC. When Pia taught this topic in her aligned lesson, she viewed the CK and PCK from this SSC lesson as less useful, since it was taught with a fairly high level of detail. She made more use of the students' textbook and online videos in planning the lesson. Pia thought she benefited little from advanced CK in SSCs. Pia provided an example of the kind of instruction she benefited from: “Like ‘let's learn about transitions between states of matter.’ And we had the same illustration as they [school kids] have in their textbook and we learned how we can work with it in a practical way.” In Pia’s opinion, the useful components of the SSCs were those directly applicable to the science content level of the classrooms she was preparing to teach.

Knowledge of students’ understanding of science

For Pia and Tina, knowledge of lower secondary students gained from SSCs played a critical role in the design of their aligned lessons on astronomy. A SSC instructor had highlighted a book chapter that stated astronomy is a topic that is often interesting for both genders. This knowledge, accompanied with knowledge of common misconceptions about the universe, guided their lesson design. Pia read about student misconceptions on why we have seasons in SSC literature, which greatly informed her lesson design. She stated, “Many science textbooks state that 15-year-olds do not understand why we have seasons. They believe it is about us being closer to or further from the sun, and not that it is the angle.” Tina had also participated in an SSC activity challenging her own misconception of the cause of seasons. She stated, “That is a typical misconception. I could agree with that [misconception] too if it was not illustrated to me.” This shows that a SSC focus on student misconceptions also improved the PSTs’ own CK. Tina clearly stated what difference SSCs made to her knowledge for teaching when reflecting upon her unaligned lesson on animal cells, “Some topics are well presented to us and some are not. We have talked about student misconceptions in almost everything we went through [in SSCs]. In this [animal cells], we have not received instruction, and therefore nothing about misconceptions.” Here, she emphasized the value of discussing common student misconceptions in SSCs as a major component that made a difference to her professional development.

Knowledge of topic-specific instructional strategies

Several of the instructional strategies enacted in PSTs' aligned lessons were drawn from SSCs. For example, Jakob learned how to distill crude oil from his SSC instructor. This included knowledge about safety issues related to the specific experiment: "The only risk here was getting hot oil over oneself. The temperature would be too high in the first distillation, but the second could be a little bit high." Pia and Tina's aligned lessons were largely built on knowledge of topic-specific strategies from SSCs. Pia used her notes from SSC lessons about stars as a rationale for emphasizing the fusion of hydrogen to become helium in her instruction on the birth of stars. For Tina, two of the main strategies in her lesson on moon phases and seasons were from a SSC astronomy lesson. She used a moon phase demonstration that was shown in a SSC. She also used a Tellurium, a model of the sun, moon, and earth, about which she stated:

> It's an extremely funny thing. I was so fascinated when we had that in teacher education. You get it so clear and visual without having to show a video where you afterwards must explain what happened. Because films often require a recap or summary. We can talk while looking at this.

The PSTs readily made use of the instructional strategies for specific topics that they experienced in SSC lessons.

Knowledge of science-specific instructional strategies

In both aligned and unaligned lessons, the PSTs benefited from knowledge of instructional strategies from SSCs. Such knowledge was transferred across science topics. PSTs benefited from use of models, practical work, and inquiry implemented as a way of learning in SSCs, and not just presented as a toolbox for future use in classrooms. Jakob stated that practical work in SSCs made the greatest impact on his knowledge for teaching science. He stated:

> I have understood a lot more about how to perform practical work, which kinds of practical work there are, and the importance of doing and focusing on the work afterwards. That the final part is where students learn. Earlier, I did not know the importance of that part. And through the program we have actually seen various kinds of practical work.

As shown in this example, SSCs facilitated PSTs in selecting instructional strategies suitable across science topics.

Self-efficacy for science teaching

PSTs perceived that the SSCs gave them increased self-efficacy for teaching science which was related to learning CK and PCK. Conversely, the participants described a lack of confidence in teaching topics not covered by prior SSCs, particularly if they had no experience with the topic since their own compulsory school. Despite spending hours researching and learning about hydrocarbons and alcohols before teaching his unaligned lesson, Jakob stated "I do not feel that I am much ahead of students in this topic [alcohols] … I miss the certainty. … Since I am uncertain, I am influenced towards following the textbook." Jakob's lack of CK restricted his ability to deliver a pedagogically sound lesson about alcohols. In the SRI reflecting on her unaligned lesson on animal cells, Pia stated: *"*I feel seen through because I am very conscious that I am not confident in this. I never had biology myself. Last time I learned this was when I had their [students'] textbook myself at school.*"* On the positive side, experience with laboratory experiments from SSCs increased Jakob's self-efficacy in carrying out experiments in his aligned and unaligned lessons. He stated: *"*We did quite a lot of laboratory stuff in teacher education. So, one become more confident at the lab.*"* Self-efficacy was partly transferred to new topics, but also gained as knowledge and experience accumulated throughout the teacher education experience. Despite uncertainty on the topic in his unaligned lesson, Jakob stated, "I have got more self-confidence in teaching. If this was the first year, I would have been more nervous." Jakob felt that the combination of SSCs and school practica helped him develop his self-efficacy as a science teacher.

Lastly, PSTs' self-efficacy was evident during observations of the lessons. Jakob enacted experiments in both lessons, as suggested by his mentor teacher. In the unaligned lesson, he had students burn alcohols and observe differences in flame color, although he thought the experiment was of little relevance to the topic at hand. In his aligned lesson, he had enough confidence to replace the suggested distilling of Coke with the more relevant distilling of crude oil. In Tina's aligned lesson, she got a question about whether the South Pole gets midnight sun or not. She did not know the answer, but instead of turning to her peer PSTs and mentor teacher for answers (as she had in the unaligned lesson), she carried out a quick inquiry using the Tellurium. She did not arrive at a final answer to the question but appeared more confident in exploring the question in comparison to a student question she had in her unaligned lesson. This provided evidence that SSCs contributed to PSTs' self-efficacy for exploring questions rather than quickly giving a correct answer.

Discussion

In this study, we look at the effects of SSCs up to two years later as three PSTs plan and teach lessons in their practica. Through the comparison of aligned and unaligned lessons, we show how SSCs had an impact on the PSTs' science teaching practice and perceptions of self-efficacy. This study contributes to the literature as earlier SSC-related studies were limited to showing CK and self-efficacy gains based on tests and interviews conducted at the end of a SSC. One exception is Etkina (2010), who followed PSTs into classrooms after they completed SSCs, and reported an increased ability to notice students' understandings and engage them in active learning of physics. However, Etkina (2010) did not compare the teachers' SSC-aligned lessons with unaligned lessons, as we did in the current study. From our comparisons, we add to her findings of the impact from SSCs; PSTs enacted more instructional strategies that were informed by knowledge of students' understandings in lessons aligned with SSC lessons. Further, we extend her work by adding nuance to research on classroom impact from SSCs. Through video recordings, lesson plans, and SRIs with PSTs, we identified they used more instructional strategies and rationales based on science- and topic-specific PCK in lessons aligned with SSCs compared to the unaligned lessons. Lastly, our study contributes PSTs' perceptions on how they drew on SSCs in their teaching practice. In summary, our study addresses a knowledge gap about whether and how PSTs use what they learn in teacher education in classrooms (Cochran-Smith & Villegas, 2016; Jenset, 2018).

The study also responds to the call for research on how science PCK develops and transforms in classroom practice (Alonzo et al., 2012). From our study, we identified the transformation of collective PCK from SSCs, via PSTs development of their own personal PCK, to enactment in classrooms. This transformation represents the potential of SSCs supporting PSTs in connecting theory and practice — a major challenge in teacher development (Grossman et al., 2009; Thompson et al., 2013). The clearest connections were from SSC lessons where course instructors went into depth discussing PCK for teaching specific topics for grade 5-10 classrooms, including a focus on students' understanding of the topic and modeling of student-centered instructional strategies. In SSCs, PSTs became aware of common misconceptions and strategies to challenge these misconceptions. Consequently, some of the aligned school practicum lessons were designed to address specific students' misconceptions. Pia and Tina's reasoning for their lessons on space are clear examples of the impact SSCs can have on teaching and learning. In an SSC, Pia and Tina learned about common misconceptions related to space. They used this information as they designed and taught their lessons. Such responsive teaching is known to be challenging for PSTs (Sun &

van Es, 2015). The contrast between unaligned and aligned lessons indicates that building on students' prior knowledge was influenced by SSC experiences rather than mentor teacher advice. Our findings also add to PCK integration literature as we show that SSCs can support PSTs in adapting instruction based on student ideas. While all three PSTs used more reform-oriented teaching practices in their aligned lessons, SSCs made a greater difference in Pia and Tina's teaching. This could be explained by Jakob's mentor teacher's instructions for his lesson planning. In stimulated recall interviews, Jakob explained how he would have designed the lessons from his own pPCK if not constrained by the mentor teacher.

Beyond describing their rationale for their instruction, PSTs shared perceptions on how their instruction was supported by SSCs. All three of them stated that SSCs made an impact on their teaching. PSTs mentioned learning CK in SSCs as useful, but they emphasized their PCK learning. They highlighted opportunities to learn PCK from SSC instructors teaching science content at the level of the students they planned to teach (grade 5-10). This finding responds to calls that teacher education should be oriented towards classroom practice (Cochran-Smith & Villegas, 2016; Darling-Hammond et al., 2017; Menon & Sadler, 2016).

Our findings indicate that developing teachers' self-efficacy for teaching science is possible through SSCs. The PSTs reported and demonstrated a higher self-efficacy in science teaching as a result of SSC experiences. Jakob, while constrained in his enactment of PCK, was the PST with the strongest statements on SSCs strengthening his self-efficacy. He highlighted inquiry-based teaching in SSCs as beneficial to his self-efficacy for teaching science. His competency and self-efficacy for leading lab sessions was transferred across topics. Menon and Sadler (2016) highlighted the importance of gaining self-efficacy early in teacher education programs and also found PST's increased self-efficacy at the end of a physics SSC. In the current study, we added to this knowledge as we explored how alignment between SSCs and school practica helped PSTs increase their self-efficacy for science teaching.

Limitations

Findings from the current study cannot be generalized, as it is a case study with a limited number of three participants. We originally planned to have a larger number of participants, but in the end, only three participants taught both an aligned and unaligned lesson. Although the data was rich and from multiple sources, the study is also limited to the comparison of one aligned and one unaligned lesson taught in the practicum. Also, the two mentor teachers differed in their input on the lesson plans and their feedback on the PSTs' teaching, as described in the context section.

Conclusion

The current study adds to the scant research base on the impact of SSCs on classroom teaching as we have found these courses contribute to the development of PSTs' knowledge and practices for science teaching. In the SSCs, the PSTs benefited from learning CK while engaging in reform-oriented strategies. Based on what we observed in classrooms, PSTs' reflections from SRIs, and their own perceptions, we conclude that SSCs can support more integrated PCK found to support students in learning (Coetzee et al., 2020; Kirschner et al., 2015). The study shows the process of connecting theory and practice as the three participating PSTs' transformed collective PCK from SSCs to their own personal PCK and enacted PCK in their practica. We show some ways SSCs support PSTs not only in learning about science and science teaching, but also enacting teaching practices. This is a needed competency (Grossman et al., 2009; Thompson et al., 2013), and Nordic teacher education programs have the potential to better support this linking of theory and practice with their use of SSCs (Rasmussen & Dorf, 2010).

Implications for research and practice

The current exploratory case study has the potential to stimulate research interest in SSCs for teachers. More studies are needed using larger numbers of PSTs, a greater number of observed lessons, and a wider variety of classroom contexts and mentor teachers. These studies should aim to see if PCK is transferred from aligned topics to new topics. Furthermore, the specific designs of different SSCs should be studied to understand their impact. In this study, we found that SSC lessons aligned with the target grade level were valued more highly by the PSTs. Finally, longitudinal studies tracing experiences from SSCs into the beginning years of teaching are needed. We are aware of the additional resources required to develop and teach SSCs. However, SSCs appear to be a good investment in teacher education as this exploratory study shows that SSCs make a difference in supporting PSTs learning to teach.

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