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

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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.

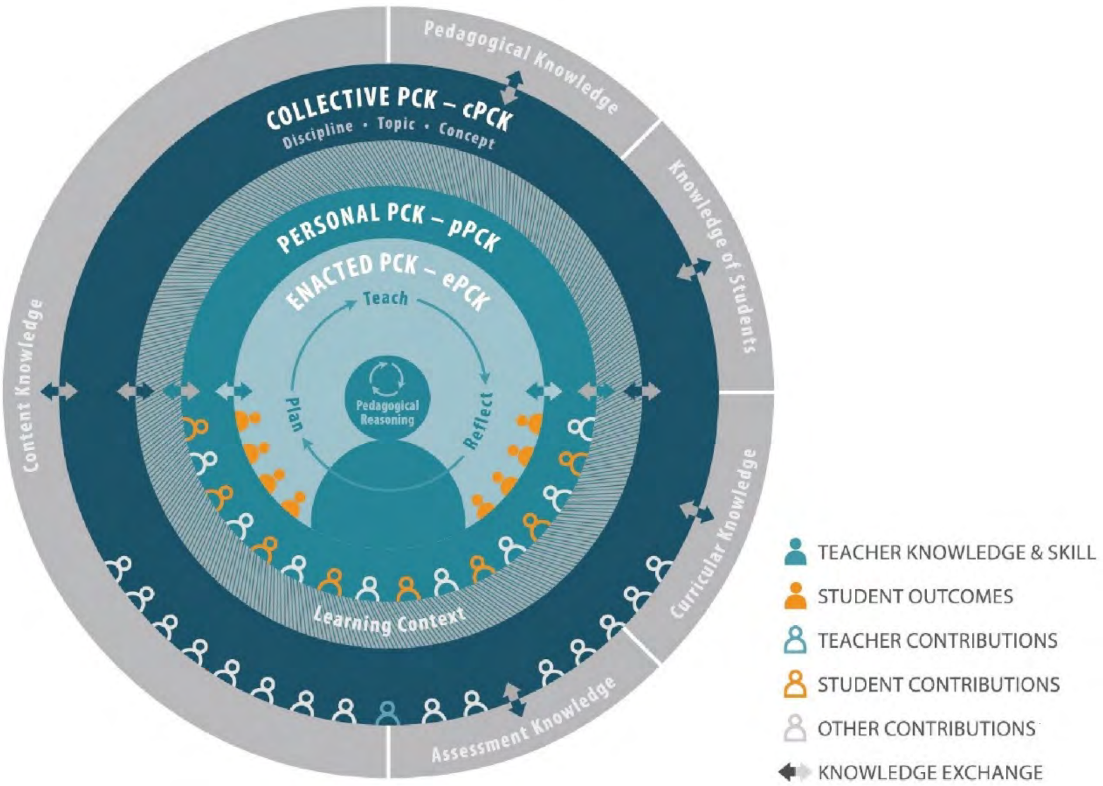

Figure 1. The Refined Consensus Model (RCM). Reprinted by permission from Springer Nature *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* by Hume, A., Cooper, R., & Borowski, A. (Eds.) COPYRIGHT 2019

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.

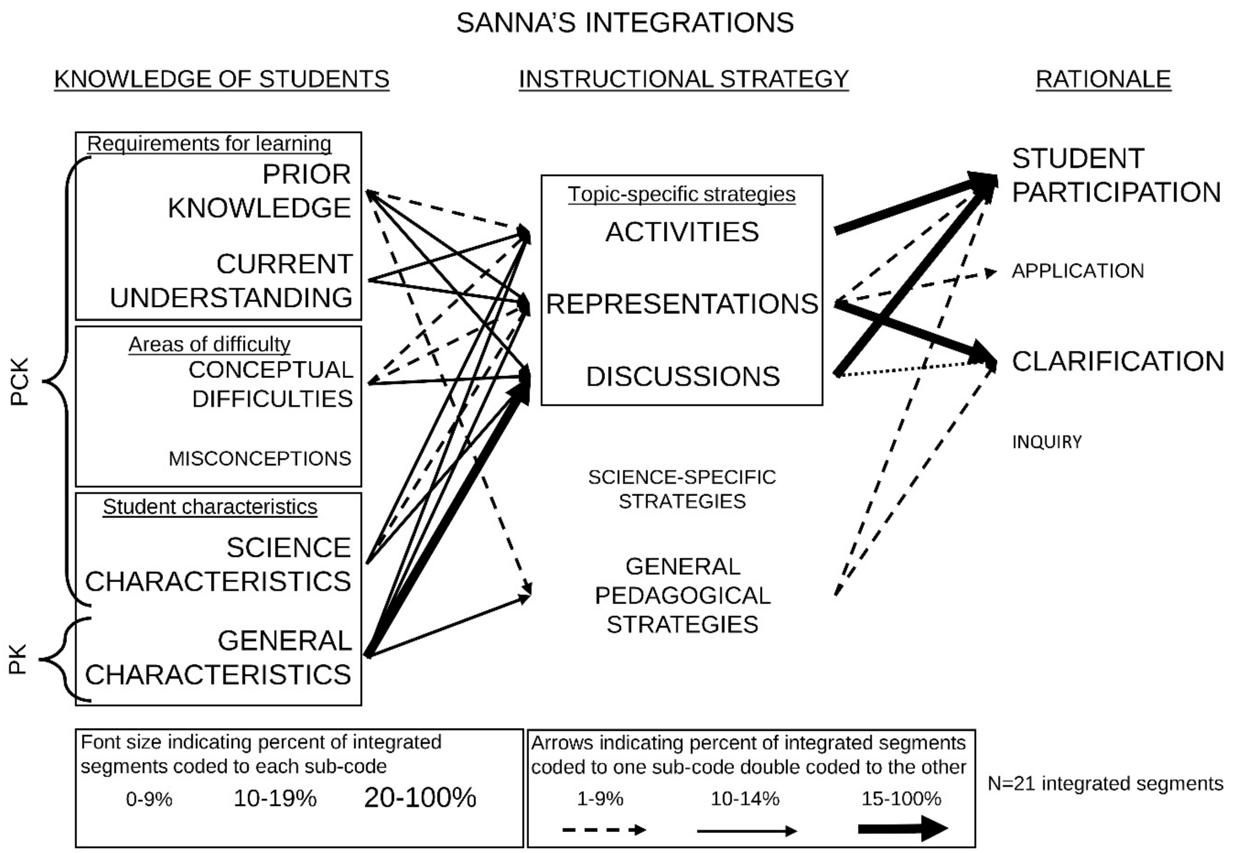

Figure 2. All integrated segment coding for Sanna, represented in a PCK map

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*