Johannes Sæleset
UiT The Arctic University of Norway
Magne Olufsen
UiT The Arctic University of Norway
Solveig Karlsen
UiT The Arctic University of Norway

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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 science instruction for beginner PSTs. All the 21 science lessons of six PSTs during the school practicum 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 practical activities with connections to science concept learning. However, the PSTs only challenged students intellectually to a moderate degree and rarely performed inquiry-based teaching. In addition, their representations of science content varied greatly in terms of quality. The results are discussed and implications for teacher education are outlined.

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

Lærerstudenters undervisningskvalitet i naturfag tidlig i utdanningen

Sammendrag

Læreres undervisningskvalitet er viktig for elevers læringsutbytte, men det finnes lite forskning 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 de 21 naturfagtimene til seks lærerstudenter som var i praksis i sitt første studieår. Videodata ble analysert med kategorier fra LISSI-prosjektets (Linking Instruction in Science and Student Impact) observasjonsmanual. Analysene fokuserte på sentrale aspekter av undervisningskvalitet i naturfag: kognitiv aktivering, tilrettelegging for diskusjon, tydelig undervisning og naturfaglig utforsking. Sett som ett kasus viste de seks lærerstudentene overraskende høye skårer 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.

Nøkkelord: naturfagdidaktikk, undervisningskvalitet, lærerstudenter, lærerutdanning

Introduction

Previous research has suggested that teachers' instructional practices are more important for student outcomes than factors such as class size, classroom climate, teachers' 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 the different variables related to teaching, student outcomes were most affected by the implementation of learning activities, particularly in science. In this paper, we use the term *pre-service teacher* (PST) for a person undergoing teacher education, while *student* refers to a child in compulsory school. PSTs spend a significant amount of time on teaching activities during periods of practicum (Cohen et al., 2013), which provide opportunities to develop their teaching. However, it is notable that a solid research base on PSTs' early teaching practices is yet to be developed. This is partly due to the low number of available studies, and partly due to their reliance on interpretations based on self-reporting (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 a lack of memory (Ronfeldt & Reininger, 2012). Video studies are tools used to overcome these issues. Video research has the potential to address the need for valid and reliable investigations of complex classroom situations by making recordings available for bit-by-bit analysis (Blikstad-Balas, 2017). Research in the field of science PSTs' practice must relate to actual classroom teaching (Ratinen et al., 2015). In the present study, we used video recordings of PSTs' instructional practices and an observation manual based on systematic assessment of video evidence to address this gap on PSTs' early teaching practices.

Theoretical framework: Instructional quality

Quality science teaching is reform-oriented. In reform-oriented teaching, teachers consider students and content rather than only the delivery of content, and they implement inquiry-based teaching (Anderson et al., 1994; Sawada et al., 2002). Reform-oriented teaching aligns with constructivist learning theories by focusing on students as active learners rather than the teacher as a supplier of information (Anderson et al., 1994).

In this study, we focus on four dimensions of quality science teaching, based on international research on what matters for student learning in science (Fauth et al., 2019; Neumann et al., 2012; Treagust & Tsui, 2014). These include cognitive activation, discourse features, instructional clarity, and scientific inquiry. The first three align with a Norwegian framework for classroom observation studies (Klette et al., 2017). Inquiries and conversations about open-ended science questions are important (Crawford, 2014; Treagust & Tsui, 2014). Thus, we considered these aspects separately.

Cognitive activation

The dimension of cognitive activation concerns whether students engage 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 has found that cognitive-activating instruction increases student achievement (Fauth et al., 2019; Neumann et al., 2012), and moderately challenging instruction motivates students (Turner & Meyer, 2004).

Discourse features

The discourse features dimension captures discussion formats and the quality of responses provided to students. In science, it is important to allow students to argue for and justify their ideas. Thus, dialogic classroom discourse eventually increases students' science competence (Neumann et al., 2012; Scott et al., 2006; Treagust & Tsui, 2014). At lower levels, discourse may 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 extension of dialogue between the teacher and students, or between students (Scott et al., 2006).

Instructional clarity

This dimension includes the clarity and explicitness of the learning goals, the presented content, and feedback on students' work and ideas. It relies on representations, explanations, and the 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 for improving students' cognitive and affective outcomes (Treagust & Tsui, 2014; Tytler et al., 2013). Constructive feedback is an important aspect in 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 experiences with scientific 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 focusing on developing scientific ideas (Abrahams & Millar, 2008; Hofstein & Kind, 2012).

Scientific inquiry

The scientific inquiry dimension concerns the appearance and quality of inquiry-based teaching in which teachers engage students in investigations. It is related to scientific reasoning, a feature of quality instruction that 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 inquiry rather than remember explanations from a teacher or a book.

Three important phases have been emphasized by researchers of scientific inquiry: asking a question and planning an investigation, carrying out the investigation and organizing data, and reasoning based on the findings to draw conclusions (Bybee et al., 2006; Knain & Kolstø, 2019). Through scientific inquiry, students can achieve cognitive gains and an increased interest in science (Crawford, 2014). They can also develop competences related to the nature of scientific knowledge (Lederman & Lederman, 2019).

The relationships between instructional quality and pedagogical content knowledge (PCK)

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), is a useful framework for science teacher knowledge (Chan & Hume, 2019). All the dimensions of instructional quality considered in this study were related to PCK, and dimensions related to general pedagogical knowledge only were omitted to ensure a clear focus on the four science-specific dimensions of instructional quality.

Knowledge of students’ understanding in science and knowledge of instructional strategies are central components of PCK. Teachers with elaborate PCK provide students with quality instruction (Fauth et al., 2019), particularly reform-oriented teaching (Park et al., 2011). Cognitively activating instruction requires PCK in the form of knowledge of students’ misconceptions and difficulties with science content and knowledge of what questions may challenge them in fruitful ways (Fauth et al., 2019; Förtsch et al., 2016). Furthermore, PCK is a foundation for quality discourse. Knowledge of students’ ideas combined with knowledge of ways to initiate scientific discussions increases the chances of desired conversations extending students' ideas about science. Considering instructional clarity, knowledge of what makes content difficult, specific misconceptions, and knowledge of instructional strategies with explanatory power in combination prepare teachers to teach clearly (van Driel et al., 2014). Finally, teachers with well-developed PCK are better equipped to deliver reform-oriented inquiry-based teaching, as their knowledge of students' understanding of science may facilitate their use of scientific inquiry (Park et al., 2011; Suh & Park, 2017).

Literature review: Pre-service teachers' instructional practices

In this section, we review the research on the instructional quality of pre-service teachers (PSTs).

Studies on PSTs' science instruction during school practicum 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 that PSTs tend to focus on themselves in their new role as teachers more than on students and their learning (Juhler, 2017; Kagan, 1992; Körkkö et al., 2016). Another finding from studies on PSTs' teaching is that classroom management is a main focus, leading them to design activities that give them more control (Zembal-Saul et al., 2002). However, when PSTs assume the role of information transmitters, they limit 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 of science teaching to the class. None was able to systematically address individual students' ideas or monitor their learning individually. Similarly, Ratinen et al.'s (2015) study of 20 Finnish PSTs showed that the participants lacked the ability to foster student thinking. The participating PSTs ignored the students' prior knowledge, although they had planned to teach dialogically (Ratinen et al., 2015). In another study, Kang (2017) investigated the lesson planning and enactment of eight PSTs. Using plans for and reports from instruction, records of teaching, and curricular materials, she found that only three of the PSTs increasingly or consistently used cognitively challenging tasks, as they were trained to do. The other five PSTs were focused on content or processes, leading them to use low-demand tasks.

In contrast, 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 periods of practicum, and in their first year in service. Using classroom observations and teacher interviews, they found that 11of 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 periods of practicum during initial teacher education and enacted early in the practicum.

Aims and research question

We addressed the need for studies on school practicum science teaching with a video study based on complete sets of six beginner PSTs' science instruction in two three-week periods of practicum in grades 6 and 7. Using a standardized video observation manual, we analyzed beginner PSTs' instructional quality in science, which was 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 practicum?*

Methods

This was 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 practicum in initial teacher education. The case study approach acknowledges the close connection between the phenomenon and context (Yin, 2014). We studied PSTs' instructional practices in science connected to the context of the school practicum.

Context

Teacher education programs for compulsory school in Norway have recently been extended from four-year undergraduate programs to five-year Master of Education programs. The PSTs participating in the current study aimed to teach students in grades 5–10. 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 primary subject. First-year specialized science courses intertwined content knowledge and pedagogy in the following topics: basic geology, chemistry, physics, biology in the intertidal zone, sexual health, waves and sound, the solar system, and technology and design. Other courses included student learning, classroom leadership, educational research, and the nature of science. All PSTs' courses focused on students' learning. For example, in their pedagogy and student knowledge course, PSTs discussed the Piagetian theory of learning in connection with lesson design, and specialized science courses used student-centered instructional strategies. The first author was a specialized science course instructor before and between periods of practicum.

To avoid conflicts of interest with the research study, the first author did not participate in the formal assessment of the PSTs in these two units. The first year of the program also included two periods of practicum: one in the fall semester and one in the spring semester. These involved approximately three weeks of mentored teaching activities and group discussions.

Participants

At the start of their first semester in the first year, all PSTs in one teacher education program cohort with science as their primary subject were invited to participate in the study. Simultaneously, two experienced schoolteachers from two different schools were recruited as mentor teachers among those engaged to mentor PSTs in the cohort. The PSTs worked in groups of three, which were organized by the program administration during the periods of practicum. Two full groups were available for this study. These were the only ones consisting exclusively of PSTs who gave consent to participate in the study and whose choice of second and third school subjects 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. We requested administrators to assign those to the two mentor teachers we had recruited. Three of the PSTs had no science specialization from high school, while the other three had two or more years of biology, chemistry, and/or geology courses. Likewise, the participants' teaching-related experiences varied greatly. One participant had no such experience, three had experience leading leisure activities for children, 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' periods of practicum took place in a grade 7 classroom with 32 students. These included two women and one man. Their female mentor teacher had more than ten years of experience. Although she was not a certified science teacher, she enjoyed teaching it. The other three PSTs (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 ten 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 periods of school practicum. All the lessons were recorded. Two small wide-angle cameras captured classroom teaching and the PSTs carried a microphone. The primary camera overviewed the classroom while facing the PST. The secondary camera captured the same events, but faced the students. In addition to the video data, reflections and observations of the context were gathered in an unstructured log.

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

Video recording in classrooms raises ethical concerns. First, the presence of cameras and researchers affects the social settings of the classrooms. To address this issue, the PSTs were asked to give advice regarding when the video recordings would be suitable. As in earlier classroom studies (Blikstad-Balas, 2017), students seemed to forget the video cameras and became accustomed to the presence of the researcher. In the 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, mentor teachers, and 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). In the development of the LISSI manual, seven researchers reviewed the literature on science teaching, leading to improved student outcomes and existing video manuals. Important features were incorporated into the LISSI observation manual. The team completed several cycles of piloting in science classrooms and refinement of categories. Thus, the development was in accordance with the procedures described in video study literature (Fischer & Neumann, 2012; Marshall et al., 2010). Through this lengthy process, the research group improved the validity and reliability of the observation manual. 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 because of their relevance to our theoretical framework.

In the coding procedure, the science lessons were divided into 15-minute segments (N = 71). Each segment was scored from 1 to 4, based on the evidence in the video and the criteria in the manual. A score of 1 indicated almost no evidence of the targeted practice, 2 indicated limited evidence, 3 indicated evidence with weaknesses, and 4 indicated consistently strong evidence. A compressed version of the video coding guide is presented in Table 1. Clear descriptions of the observable characteristics for each score strengthened the validity of the categories, and probably also the reliability of the scoring. The topics varied across lessons. In the results, we included descriptions of the teaching 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: Teacher responses and student 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]	
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.

Evidence for low-end scores (1–2)	Evidence for high-end scores (3–4)
	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-based 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. Categories selected 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 that the manual was valid, the categories were discussed and found to correspond to the observed classroom practices. The first and second authors co-coded 17% of the material (12 segments). In three cycles, the first and second authors coded identical segments using all 12 categories, discussed and revised any differing scores, and clarified the video observation manual to ensure reliable analysis of science teaching practices. The first author coded all the 71 segments based on the clarified observation manual.

The results were characterized more by similarities among the PSTs than by the detected differences. We calculated the variance of the PST average scores. Across all categories, the average variance is 0.16. This supported a focus on PSTs as one case rather than separate cases. To look for patterns in the 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 sustained attention to these concepts during the instruction. Abstract topics are not visible to perception and refer to concepts of moving parts despite being often represented statically. The topic of energy is for example considered a difficult topic because (a) energy is not visible to perception and therefore abstract, and (b) energy is “what makes something happen” and therefore a dynamic concept. A lesson would be defined as in-depth if the teacher did not avoid unpacking a difficult topic such as energy.

Results

Overview of the lessons

All lessons and scoring results are presented in a supplemental table in the Appendix. The six participating PSTs each taught three or four science lessons during the two periods of practicum. Some topics were covered in a single lesson, whereas 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 topic, depth, and duration.

Table 2. Overview of recorded lessons

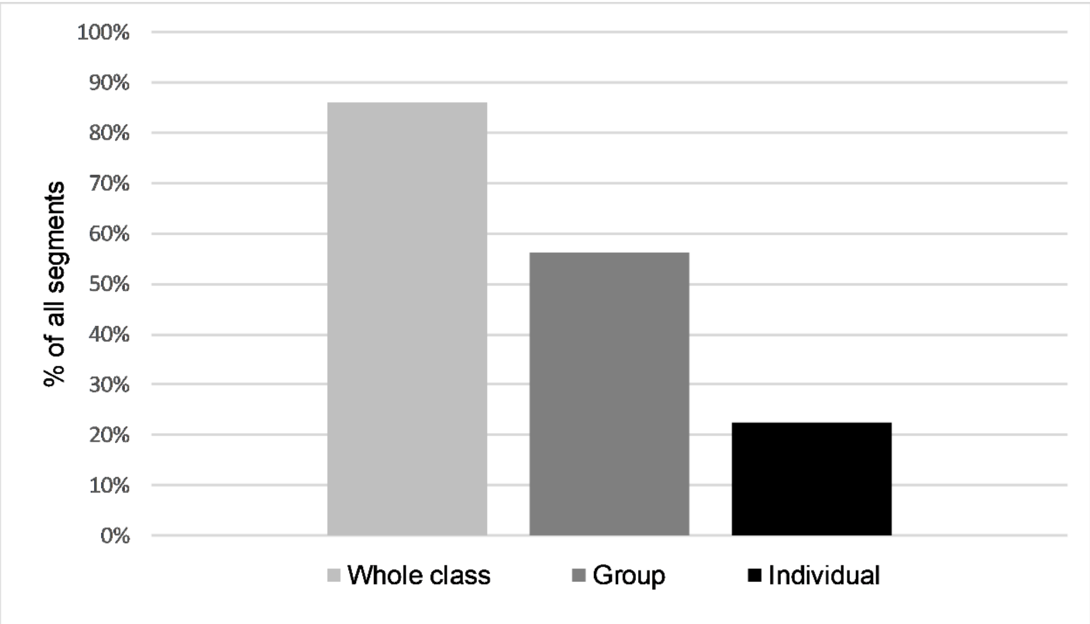
Lesson	Topic	In-depth lesson	Duration in 15-minute segments
1	Nutrients	Yes	2
2	Sexual health	No	2
3	Sexual health	No	4
4	The eye	No	2
5	The eye	No	4
6	Animals, nutrition	No	3
7	Drugs	No	5
8	Energy content in food	Yes	2
9	Sexual health	No	2
10	Sexual health	No	4
11	Male puberty	No	3
12	Energy	Yes	3
13	Energy and fuel	Yes	4
14	Energy sources	Yes	3
15	Female puberty	No	2

Lesson	Topic	In-depth lesson	Duration in 15-minute segments
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 of a lesson varied from 6 to 20 min.

The class organization (whole class, group, and/or individual) was recorded for each 15-minute segment. Figure 1 shows the 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 categories are assigned to more than half of the segments. Occasionally, the students worked individually.

Instructional quality

We analyzed the instructional quality of all segments. We present the results for all PSTs to reveal the main findings related to the four dimensions of instructional quality. Scores range from 1 (low) to 4 (high). Table 3 provides an overview of the average scoring results for each dimension of instructional clarity across all segments. It is important to note that quality instruction is not necessarily assigned high codes for every category, meaning that average scores as presented in Table 3 should be interpreted with caution.

Table 3. Average scores per dimension, all segments

Cognitive activation	Discourse features	Instructional clarity	Scientific inquiry
1.8	2.5	2.1	1.2

The average scores presented in Table 3 indicate that lessons that lessons typically showed evidence of quality discourse, while the material provided almost no evidence of scientific inquiry. The results for each dimension are presented in the following sections.

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; Figure 2). These scores were spread across 90% of the lessons, indicating that PSTs often referred to students' prior knowledge and experiences and connected them to the current lesson. In the following example from lesson 16, the PST connected the students' prior knowledge and experiences to the topic of renewable energy. First, students were asked to share their prior knowledge. The PST then connected their experiences and knowledge to the instruction.

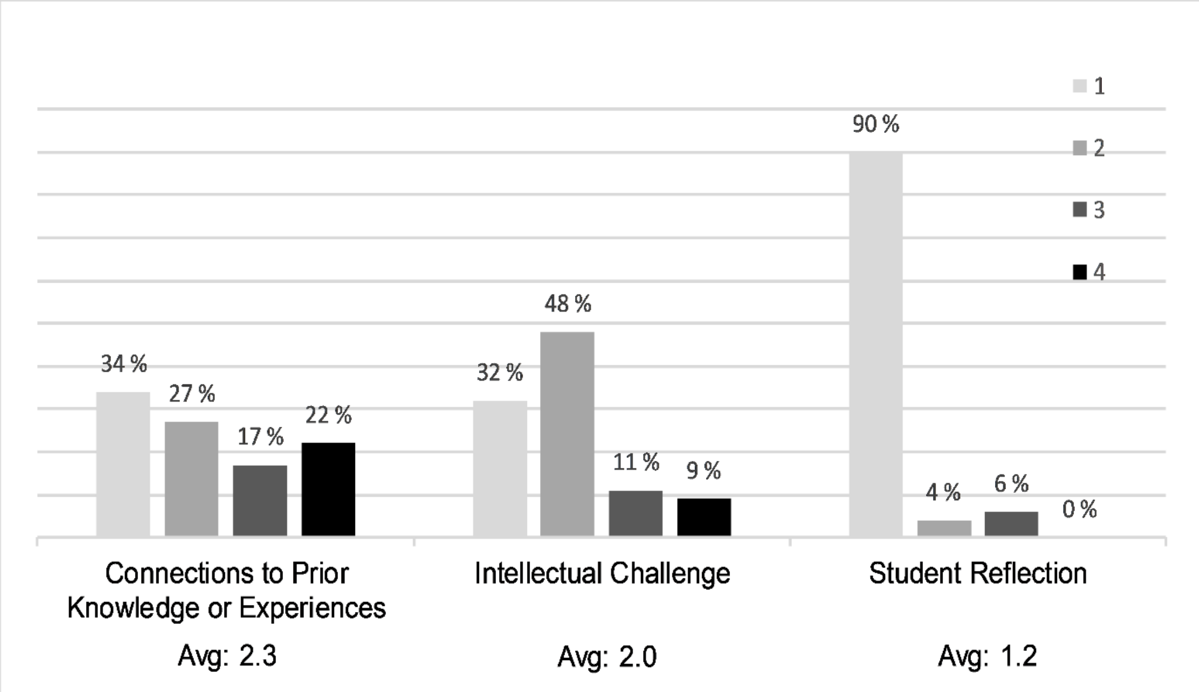
Student: In Turkey, when I was there two times ago, there was only one windmill. But when we returned this summer, there were like ten windmills.

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. Therefore, the segment was scored 4 in the *connections to prior knowledge* category.

Results on *intellectual challenge* and *student reflection* (Figure 2) indicate that PSTs struggled to make the instruction intellectually challenging and prompt students to reflect on their learning. In just 10% of the segments, PSTs initiated student reflection. The *intellectual challenge* category measures whether PSTs provide 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 (Figure 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, the 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. Coding for categories within the cognitive activation dimension across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of scores 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 and 25% of the second practicum segments (Table 4). An increase in scores for *intellectual challenge* was evident for all the six PSTs. Segments with high-end scores for *intellectual challenge* were never at the start of the lessons.

Table 4. 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%

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.

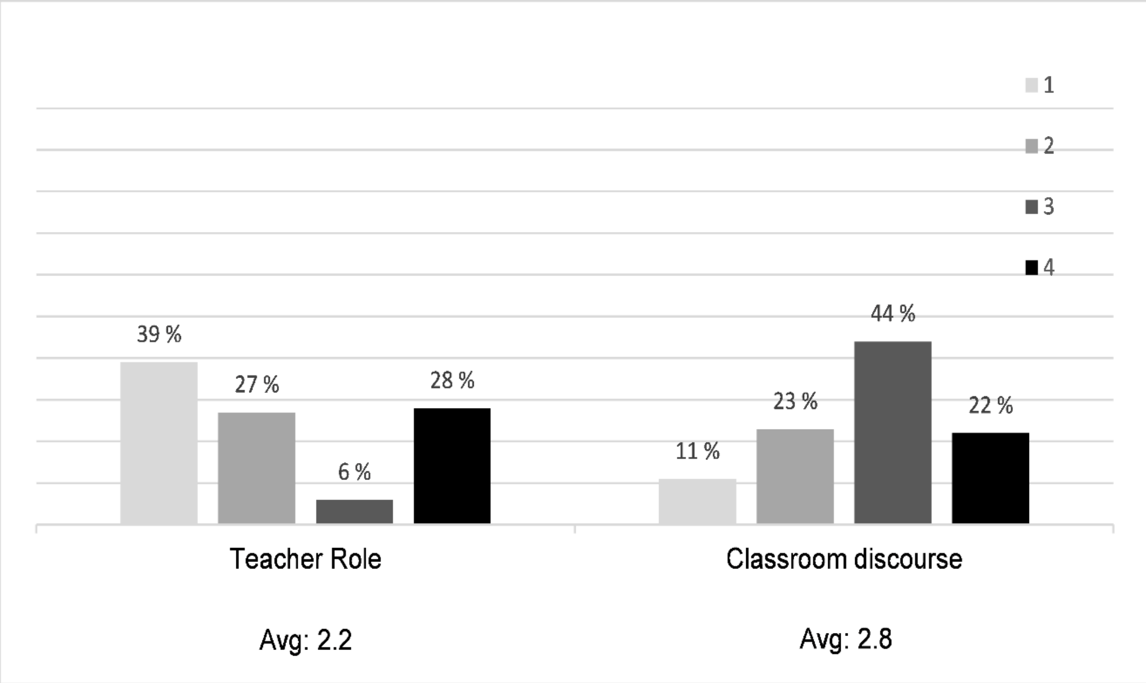
In regard to the *teacher role* (Figure 3), 34% of the segments achieved high-end scores, as the PST did not orient the lesson around herself as center of the lesson. These segments were dominated by student–student talk and cooperative solving of tasks. Student–student talk was facilitated in both group work and whole-class settings. For 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. Therefore, this segment was scored 4 on *teacher role.* Also, 27% of the segments were scored 2, making a total of more than half the segments characterized with a presence of students' internal discussions or problem-solving.

To achieve a high-end score for *classroom discourse*, communication patterns should involve students and teachers carefully listening to each other, and the teacher should tailor the dialogue to fit the students' emerging understanding. In total, 66% of the segments achieved high-end scores (Figure 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 22% of the segments (Figure 3), including a segment from lesson 14, focusing on energy sources. In this 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 during the whole-class 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 the students were picked up by the PST, which furthered the conversation. The PST guided the conversation towards energy loss to heat, and the group concluded that the system would not work.

Figure 3. Discourse features, facilitation of science discourse

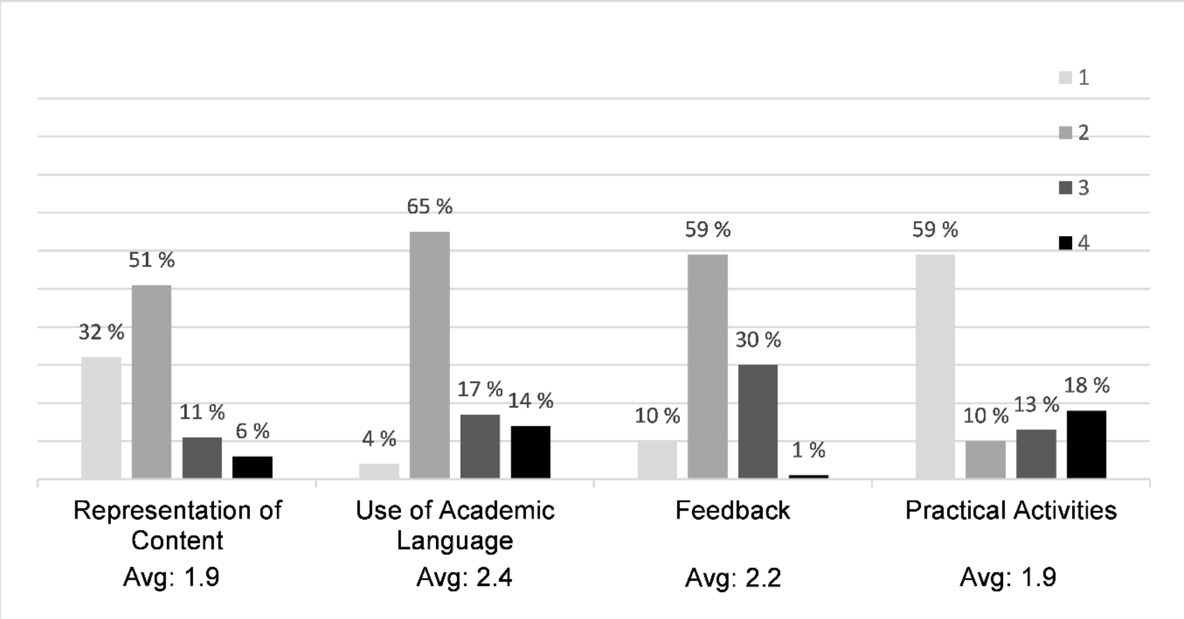


Note. Coding for categories within the discourse dimension features across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of scores across all segments. Avg: average score across all segments.

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

Illustrations, examples, models, analogies, and explanations were often absent, incomplete, or perfunctory. When 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 only 31% of the segments (Figure 4). In many lessons, PSTs hardly provided 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 the 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 because of incorrect communication about light bulbs and current in the conversations above.

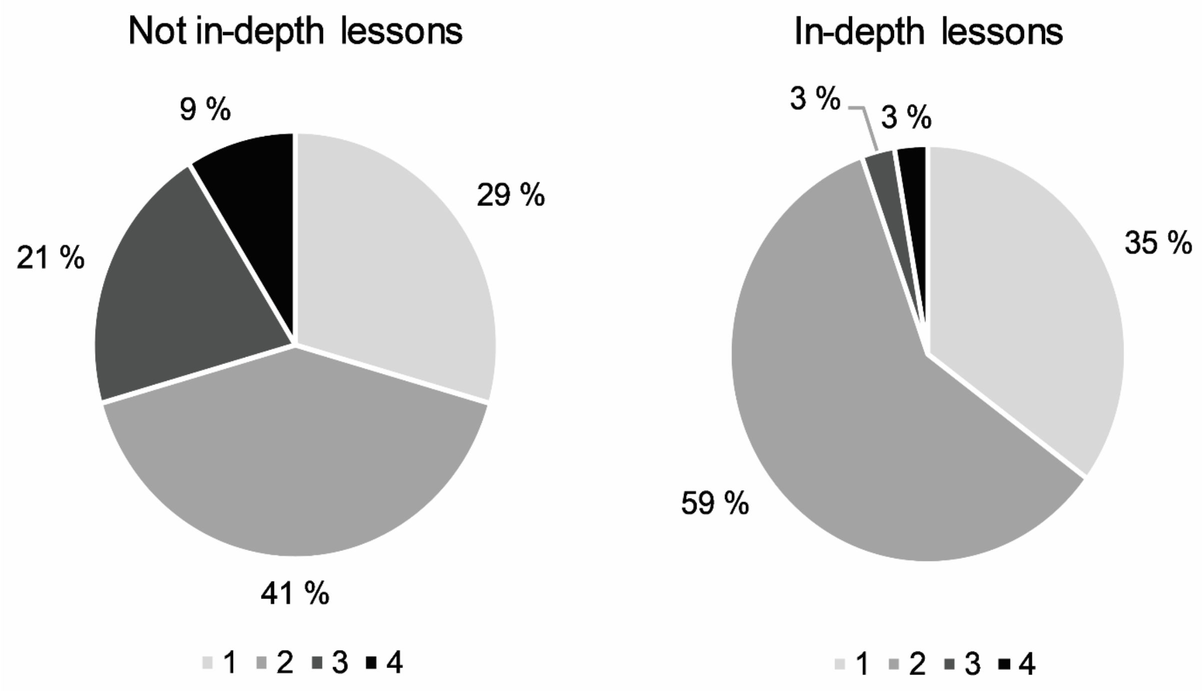
Figure 4. Instructional clarity, communication of science content knowledge



Note. Coding for categories within the dimension of instructional clarity across all segments (N = 71). 1 = lowest score, 4 = highest score. Each column represents the percentage of scores 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 (Figure 5).

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).

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 used were often accurate and clear. In the second segment, scored 4 for *representation of content*, she explained the menstruation cycle with nuances regarding its duration. She addressed a misconception about menstrual blood being different than other blood by viewing an effectful TV commercial for sanitary pads.

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 example above from lesson 15 illustrates this. The accurate and clear representations about female puberty were provided while the PST led 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 that they had limited content knowledge and scored lower on *representation of content*.

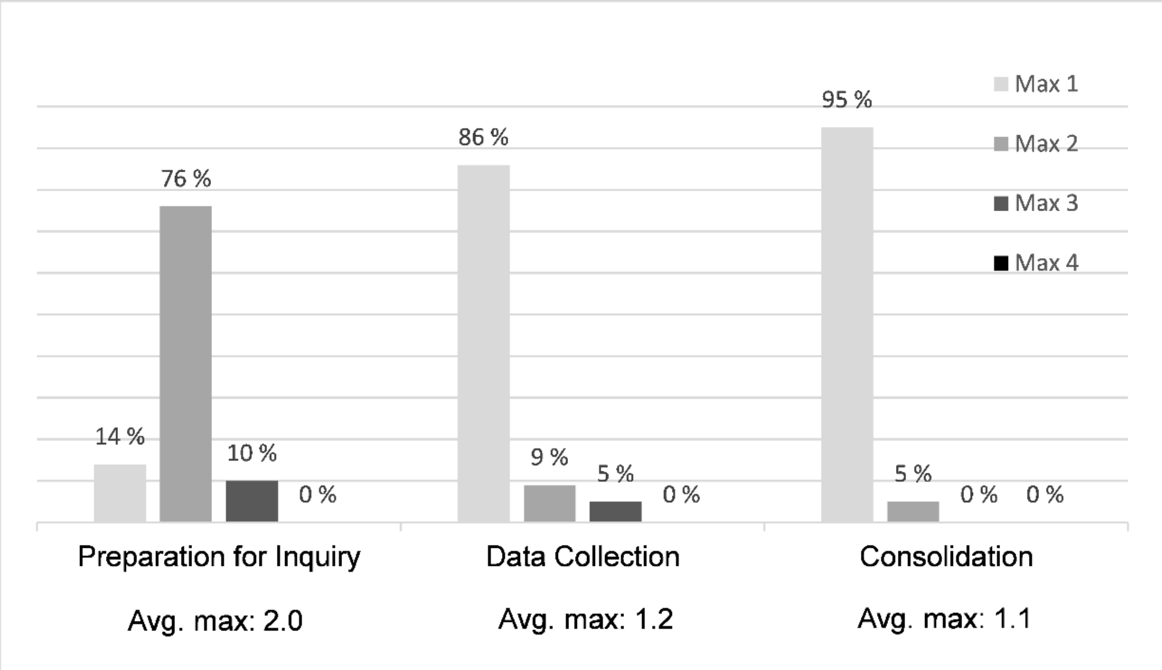
The category *feedback* focuses on the quality of the feedback provided in response to students' application of science skills, concepts, or strategies. To achieve a high-end score for *feedback*, PSTs or students should provide specific feedback on students' work or ideas that challenge them to further develop their thinking. In total, 59% of the segments scored 2 in this category (Figure 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* (Figure 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 the 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 carrots and burning the equivalent energy by jumping on their chairs. The PST analogized the activity with everyday knowledge about cars requiring refueling to drive. By linking the activity to this explanation, the PST helped the students learn the concept of energy content in food.

Inquiry-based teaching was seldom or poorly implemented

Preparation for inquiry, *data collection*, and *consolidation* (Figure 6) represent significant phases of inquiry-based teaching (Knain & Kolstø, 2019; Ødegaard et al., 2014). As inquiry-based teaching typically spans a period of time and does 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 in which students wondered about science. This has the potential to initiate inquiry work. A score of 2 for *preparation for inquiry* was awarded to 76% of the lessons. Higher scores that required formulation of researchable questions, hypotheses, or predictions were awarded to only 10% of the lessons. In regard to the two other categories, only three lessons (14%) included data collection (scores 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 used, we found little evidence for inquiry-based teaching.

Figure 6. Scientific inquiry, phases of inquiry-based teaching



Note. Coding for categories within the scientific inquiry dimension. 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

This study contributes to the field by conducting a video study of pre-service teachers' (PSTs') science instruction during school practicum. A video coding manual was useful for the analysis of the 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 practices. 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 section, we discuss the coding results for the four dimensions of instructional quality.

Cognitive activation

We found that students were seldom provided challenging tasks that prompted them to improve their thinking. An initial increase in cognitive activation from the first to the second round of data collection may indicate PSTs' ability to develop and possible impact of teacher education. From our data, quality classroom discourse seems to be related to intellectually demanding instruction. All 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, as they get the opportunity to explain and justify their thinking (Smart & Marshall, 2013). Based on the finding of little intellectually 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. In particular, beginning lessons with demanding tasks deepens 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 primarily around themselves. 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). The results from the *classroom discourse* category provide more evidence for dialogic classroom discourse. Across all segments, the average score was 2.8 on a scale from 1 to 4. Although it is difficult to compare different video studies using different observation manuals, one could say that this represents a contrast to a video study of experienced teachers in mathematics lessons, being scored at 2.2 on a scale from 1 to 7 on a similar category (Gamlem, 2019).

Instructional clarity

The PSTs struggled to communicate science content knowledge accurately and clearly 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 the segments received high-end scores for *representation of content*, and in unplanned interactions. Although exemplary representations were also identified, they seemed to be concentrated in lessons that were not classified as in-depth and during planned presentations. Furthermore, *use of academic knowledge* received low-end scores in 69% of the segments, indicating that the 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. None of the participants had a prior higher education in science. Even though the few months of specialized science courses seemed to support their development of knowledge useful for teaching, the variable instructional clarity points to a need for a broader and deeper knowledge base in content knowledge and relevant PCK. We suggest that teacher education course instructors prioritize teaching difficult topics relevant to school practicum. Teachers need domain-specific knowledge in the form of content knowledge, and pedagogical content knowledge (PCK) is necessary to support student learning (Seidel & Shavelson, 2007). Furthermore, 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 through their use of practical activities to teach science concepts. This indicates that the participating PSTs avoided a common mistake by science teachers: initiating hands-on activities without a simultaneous connection to science ideas (Abrahams & Millar, 2008; Hofstein & Kind, 2012). Our results also contrast with a Norwegian video study (Ødegaard & Arnesen, 2010) that found that in-service teachers use few practical activities and miss opportunities for scientific discussions during practical work.

Inquiry-based teaching

Inquiry-based teaching has significant potential in regard to student learning of science content knowledge and enculturation in scientific practices, and is central to science education reforms (Crawford, 2014; Norwegian Directorate for Education and Training, 2020). The near absence in the participants' periods of practicum is notable. We observed the *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 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 debates on why the potential for inquiry is difficult to exploit in science classrooms.

Conclusion and implications

We described the 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 has brought about a change from teacher-centered to student-centered teaching (Anderson et al., 1994; Sawada et al., 2002). One overarching quality of 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 and 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 because many studies on beginner PSTs have highlighted 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 out 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 into teachers from scratch by teacher educators. Future research should further investigate the 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, the PSTs hardly enacted any inquiry-based teaching, scientific language was poorly explained, and the representation of content varied too much in quality. One possible implication is to target efforts in teacher education programs towards topics to be taught during school practicum. This may provide PSTs with opportunities to gain and use knowledge related to teaching specific science topics, leading to quality learning opportunities for students in practicum classrooms. The increase in cognitive activation from the first to the 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.

About the authors

Johannes Sæleset is a PhD student in science education. His PhD project focuses on pre-service science teachers' development and use of knowledge and practices for quality science teaching in grades 5–10.
Institutional affiliation: Department of Education, UiT The Arctic University of Norway, P.O. Box 6050 Langnes, 9037 Tromsø, Norway.
E-mail: johannes.saleset@uit.no

Magne Olufsen is a professor of science / science education. His research focuses on quality in teacher education, student-active teaching and the link between teaching and learning in science.
Institutional affiliation: Department of Education, UiT The Arctic University of Norway, P.O. Box 6050 Langnes, 9037 Tromsø, Norway.
E-mail: magne.olufsen@uit.no

Solveig Karlsen is an associate professor of school science / chemistry. Her research focuses on quality in teacher education and inquiry-based teaching.
Institutional affiliation: Department of Education, UiT The Arctic University of Norway, P.O. Box 6050 Langnes, 9037 Tromsø, Norway.
E-mail: solveig.karlsen@uit.no

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Appendix

Supplemental Table
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.