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Student teachers' challenges addressed by science didactics when reflecting upon teaching at a science centre

Abstract

This study aimed to examine student teachers' challenges addressed by science didactics in a fieldwork assignment at a science centre. From a teacher educator perspective, it is central to understand how student teachers' theoretical understanding of science didactics comes into play in practice. The empirical material consists of video-stimulated reflections on teaching science at the science centre. By using a didactic model, the influence of artefacts as representations emerges as the most prominent challenge with science didactics at the science centre. This, together with the identified challenges: knowledge about school students' science understanding, making science content accessible, and the complexity of asking questions, indicates that the didactic model becomes a valuable analytical tool. To create didactical situations in teaching practice, the didactic model provides a powerful 'thinking tool' for student teachers – as well as teacher educators in their practice.

INTRODUCTION

The present study aimed to examine student teachers' challenges addressed by science didactics, as identified through video-stimulated reflections (VSRs) on teaching science in an out-of-school science environment. The interest is on the subject matter didactics of natural sciences (Kansanen, 2009) and is in this study referred to as science didactics. It concerns the particular knowledge of

teaching and learning the science subject's chemistry, physics, and biology (Kansanen, 2009; Olin, Almqvist, & Hamza, 2017). Research has demonstrated that student teachers learn science didactics on a theoretical level but have difficulty turning this knowledge into teaching situations conducive to students' learning (Grossman, Hammerness, & McDonald, 2009; Hammerness & Klette, 2015).

Teacher education aims to facilitate student teachers in developing powerful ways of understanding science didactics and integrating this knowledge into their teaching, thus facilitating their school students' learning. As researchers and teacher educators, we have an idea, based on our experiences and knowledge, of what science didactics encompasses and what aspects we want student teachers to discern and master so as to make this knowledge their own (Marton & Booth, 1997). However, it may be difficult to detect student teachers' challenges with science didactics, as we often approach it from a theoretical perspective, in university-based courses. We as teacher educators need more opportunities besides observing student teachers' clinical practice at school to understand how they integrate theoretical and practical knowledge of science didactics, in situ with school students. In other words, learn how they create didactical situations (Brousseau & Balacheff, 1997), which is described by Brousseau and Balacheff (1997) as a situation where the teacher engages students in content and pedagogical rich activities, so that they gain a deep understanding of the content.

The inclusion of artefacts in a didactical situation acknowledges the influence of material resources and is illustrated in a model by Rezat and Sträßer (2012). Therefore, in this study, a didactical situation is created by the student teachers' arrangement of an interplay between the students, subject content, and artefacts (Nyman, 2017). From a socio-cultural perspective, Jakobsson (2012) suggests that we need to include the interaction between humans and artefacts to understand the learning processes. To develop powerful ways of understanding and use their science didactics knowledge in practice, student teachers need to become aware of different ways of understanding the science content, school students, and teaching situations (Marton & Booth, 1997). For this reason, the present study focuses on student teachers' awareness of science teaching challenges addressed by science didactics and how didactical situations are constituted in relation to these challenges.

One way to integrate science didactics knowledge into practice in university-based courses in teacher education are to collaborate with out-of-school science environments (e.g., science centres, science museums, botanical gardens, and aquariums). Findings from previous studies have shown that such collaborations offer unique learning opportunities for student teachers (McGinnis et al., 2012). These opportunities involve developing knowledge of science content as well as the confidence to teach and reflect on their own teaching (Avraamidou, 2014; Gupta & Adams, 2012; McGinnis et al., 2012). The present study starts from a partnership between teacher education at a Swedish university and a local science centre. The aim is to examine challenges, addressed by science didactics that student teachers experience when teaching science at a science centre. The word *challenge* describes situations that include experiences of conflict between two or more actions, each of which produces different consequences for teaching. The aspects of science didactics that form the basis of our understanding of teachers' unique knowledge base are those that have been described in science education research (Andersson, 2011; Kansanen, 2009; Wickman, 2018; Zetterqvist, 2003).

To emphasize the role and influence of the exhibition environment, we apply the adapted tetrahedron suggested by Nyman (2017) and initially developed by Rezat and Sträßer (2012). The didactic model foregrounds aspects important for constituting a didactical situation and considers the role of the material resources of the exhibition environment. With the above reasoning in mind, our research questions are as follows:

- What challenges, addressed by science didactics, can be identified by student teachers when reflecting on their science teaching at a science centre?
- How are didactical situations constituted in relation to these challenges?

BACKGROUND

Using out-of-school science environments in science education

In teacher education, it is central that student teachers have recurring opportunities to practice planning and teaching science in the classroom and outside. Research demonstrates that by integrating out-of-school science environments in science teacher education, student teachers are offered unique opportunities for learning science and teaching science (Avraamidou, 2014; McGinnis et al., 2012). However, teaching in an out-of-school science environment such as a science centre entails challenges for student teachers in several ways. In contrast to the science classroom, the centre's material-rich and multi-sensory environment is designed, displayed, and controlled by others to attract interest and encourage free-choice exploration of and interactions with scientific phenomena (Rennie, 2014) and not primarily to facilitate learning of specific science curriculum topics.

Furthermore, when teachers take their students on school trips to science centres, they often have in mind the formal school curriculum for a particular age group and a specific science topic. Thus, they need to be thoughtful about what material resources in the exhibition they use to attract students' attention and explain particular science content. However, this requires knowledge about what resources are available for teaching particular science content and discerning the scientific phenomena and principles that may be hidden in the exhibition (Nyberg, Hipkiss, & Sanders, 2019). At the same time, teachers need to attend to what they perceive as exciting and relevant in the exhibitions relative to the science content and students. In sum, out-of-school science environments, pose several challenges for student teachers, as well as for teachers wishing to teach specific science content outside the classroom.

Didactics and subject matter didactics

In this study, we use the term didactics, which is a translation of the term *didaktik*, which in the Scandinavian countries and Germany (Kansanen, 2009; Klette, 2007; Riquarts & Hopmann, 1995) describes both the science of the teaching profession and the professional knowledge teachers possess (Osbeck, Ingeman, & Claesson, 2018). Didactics is characterized by a close relationship between theory and practice in educational processes and stresses the complexity in the teaching, studying and learning processes. As regards teaching a particular subject, for example, biology, the teacher always needs to consider the subject's content in relation to theory and practice. Subject matter didactics helps professional teachers teach students a certain subject content so that they will learn this content (Olin et al., 2017). Sjöström (2018) argues that, if subject matter didactics is to be relevant, it needs to connect to the subject's content, teaching practice, and educational theories. As a research area, subject matter didactics is extensive and complex, with several different subject traditions existing side by side, partly intertwined (Andersson, 2011; Kansanen, 2009; Sjöholm & Kansanen, 2017). Subject matter didactics is an area of knowledge where educational research meets subject content and school practice. One can approach subject matter didactics from three angles: a subject, a practitioner, and pedagogical research (Sjöström, 2018). Science didactics is a specialisation within subject matter didactics that includes didactical issues of teaching and learning in chemistry, biology, and physics (Kansanen, 2009) and constitutes the focus of this study.

To understand the interplay between the teacher, science content, and student, Brousseau and Balacheff (1997) introduced the didactic triangle. The didactic model depicts the importance of establishing the goals of teaching in relation to students' prerequisites – as well as striving for a balance between scientific ideas and principles, understanding of the natural world, the working methods of science, and knowledge of science in society. To the extent that didactic models can be used as thinking tools for teachers, they can serve as analytical lenses for researching teaching situations (Wickman, 2018). Brousseau and Balacheff (1997) describe didactical situations as the teaching-learning that supports student engagement with the content, as illustrated by the didactic triangle (Nyman, 2017). In a didactical situation, one cannot understand the teacher's actions without simultaneously understanding the students' actions and the content's knowledge structure and function. It is an undividable system, described as the didactical triangle - teacher-student-subject content (Brousseau

& Balacheff, 1997), where the relationship between the three angles is understood as a whole. Thus, by adding a fourth vertex to the didactic triangle, the role and influence of the material resources are taken into account in the didactical situation (Rezat & Sträßer, 2012).

The didactic tetrahedron

To emphasize the role and influence of the exhibition's material resources as part of a didactical situation, the didactic model developed by Rezat and Sträßer (2012) is used in this study to analyse these didactical situations. Although *artefacts* are referred to as human-made cultural tools or designs (Béguin & Rabardel, 2000), we utilise the notion of artefacts as human-designed and natural physical objects and can be viewed as material resources in the science centre environment. Living organisms and objects (natural and human-made) are selected and placed in the exhibitions to create particular features (e.g., authentic sceneries of real-world natural habitats and scientific explanatory models) that can be viewed as artefacts. Thus, when teachers act upon these artefacts in their teaching of specific science content, the artefacts become representations (Rezat & Sträßer, 2012) of science phenomena in teaching. According to Rezat and Sträßer (2012), students and teachers often share the same *artefacts* in the classroom, such as textbooks, digital resources, and negotiation of the meaning of certain content. It is possible to consider *artefacts* as something that affects the whole class and not only the individual.

Artefacts constitute the fourth vertex in the didactic model, and the didactic triangle thus becomes a didactic tetrahedron. In the didactic tetrahedron, the *artefacts*, *students*, *teachers*, and the *subject content* influence and shape each other and the didactical situations as a whole. Although the expanded version of the tetrahedron considers the impact of institutional, cultural, and social circumstances on teaching and learning mathematics, we use the tetrahedron in a narrower sense, as an analytical tool, similar to the adapted model proposed by Nyman (2017) (see Figure 1).

Figure 1. The figure demonstrates the adapted model proposed by Nyman (2017), initially developed by Rezat and Sträßer (2012).

In this study, we use the didactic tetrahedron to analyse the challenges addressed by science didactics that student teachers experience when reflecting on their science teaching at the science centre.

METHOD

Context of the study

The current study's context is a course assignment given to student teachers in three specialisations, in two different teacher programmes at the University of Gothenburg. Two of the specialisations prepare student teachers for primary school, one for lower primary (pre-school class and years1-3) and

the other for the upper primary school (years 4-6). The third specialisation concerns the lower and upper secondary school (Years 7-9, and 10-12) and is a short supplementary teacher programme. The assignment, which was carried out by student teachers in the three teacher specialisations, involves working in small groups, planning and implementing science lessons and as reflecting on implementation at a local science centre (see Table 1). Student teachers' reflections on the implementation, a science lesson conducted twice with different groups of school students constitutes the empirical basis in this study.

The student teachers preparing for primary school carried out their assignment within a university science and technology course in science didactics. The student teachers preparing for secondary school carried out their assignment within a one-week internship at the science centre. Both these groups of student teachers were expected to develop knowledge in science didactics during their courses and in the practical teaching situation at the science centre. The course assignment at the science centre aimed to allow student teachers to learn more about the different exhibitions. Furthermore, encouraging them to reflect on what opportunities and difficulties such environments entail in teaching and learning science and technology. Even if the two groups of student teachers were preparing to teach different age groups of school students and have different backgrounds, the study's interest is directed to the challenges they experienced when teaching science at the science centre and how these challenges relate to aspects of science didactics.

Table 1. The table presents an overview of the participating student teachers, year in education, educational context, assigned exhibition, and theme.

Student teachers participating in the VSRs	Year in teacher education and program	The educational context of the assignment	Assigned exhibition and theme
'Life in space group' - 3 student teachers preparing for teaching science in pre-school class and years 1-3 (students' age 6-9)	Fifth semester of a 4-year program	The assignment was given within a subject didactics course in science and technology.	The space exhibition in which the International Space Shuttle (ISS) is a salient feature. The theme was 'living in space.'
'Ecosystems group' - 4 student teachers preparing for teaching in upper primary school, years 4-6 (students' age 10-12)	Fifth semester of a 4.5-year program	The assignment was given within a subject didactics course in science and technology.	The living rainforest exhibition, featuring a South American rainforest. The theme was 'ecosystems.'
'Evolution group' - 3 student teachers preparing for teaching in lower and upper secondary school, years 7-9 and 16-19 (students' age 13-19).	Half-way through a 1-year teacher program for students with an academic degree in any of the science subjects and mathematics	The assignment was given within a 1-week internship at the science centre.	The tropical aquariums and terrariums. The theme was 'evolution.'

Data

The empirical material is based on data from a recent study by Williams (2020), who explored an approach to video-stimulated reflection (VSR) to facilitate student teachers' collaborative, reflective practice. The VSR interviews were a part of more extensive research concerning student teachers'

planning and implementing science lessons with school students at the science centre. The focus of the study by Williams (2020) was to create conditions for a reflective space in which student teachers could articulate, share their concerns, and reflect *on* and *for* possible future actions in similar teaching situations. The empirical material encompassed audio recordings of video-stimulated reflection interviews (VSRs) with three groups of student teachers about two months after completing their course assignment at the science centre, in 2016.

The timing of the VSRs was primarily pragmatic and depended on the researcher's (one of the authors) and student teachers' availability. Although the elapsed time may have limited the student teachers' ability to recall what they were thinking at the time of teaching at the science centre, this was not the main purpose of VSRs. Rather enable a reflective process, in which they could 'step outside' their practice, view it from a 'distance' and share teaching concerns. Also, to provide the student teachers the opportunity to think about their science teaching from different perspectives in light of their progression in teacher training (Williams, 2020).

The role of the facilitator (the first author) was critical. On the one hand, the facilitator must evoke a reflective process by disrupting taken-for-granted conceptions of science teaching. On the other hand, he or she need to take a step back, listening, and allowing the student teachers to govern their reflective discussions (Williams, 2020). Therefore, the semi-structured interview protocol developed for the VSRs was only used as background support (Lee & Loughran, 2000) to allow the student teachers autonomy to stop the video, share their concerns, and start a discussion.

The audio recordings were transcribed verbatim and included introductory discussions about the practice of planning and teaching at the science centre. They also included student teachers' comments, concerns, and reflections on their science lesson, which they conducted twice (first lesson and second lesson) with different students. In addition, the audio recordings included a subsequent discussion about the second lesson in relation to the first. In the VSRs, the focus was on student teachers' reflections concerning aspects of teaching at the science centre that they perceived as challenging (Williams, 2020). The present study, which does not concern the reflective process as such or the approach to video-stimulated reflection, is based on the transcripts of the three groups of student teachers' VSRs on their first and second lessons at the science centre (a total of 6 hours). In contrast to the study by Williams (2020), the current study focuses on student teachers' concerns about teaching or opening up a particular science content for a group of students. The empirical material used comprises transcriptions of the following parts of the VSRs interviews:

- Video-stimulated reflections on the first lesson, including subsequent discussion (about 60 minutes). The student teachers could stop the video footage at any time to share their teaching concerns. Each concern could then start a discussion or be left unexplored by the group. It was also possible that another student teacher in the group shared his or her concern, which could become the topic of discussion.
- Video-stimulated reflections on the second lesson, including subsequent discussion (about 60-70 minutes). The same procedure of stopping the video footage was performed as in the first lesson. However, in the subsequent discussion about the second lesson, the student teachers were asked to share their thoughts and feelings about the second lesson in relation to the first.

Analysis

The present study started with an interest in what student teachers direct their attention to when viewing video footage of their science teaching to students at a science centre. This was followed by a focus on identifying units of reflection in the VSRs on the first and second lessons. Reflection could arise in the conflict between what the student teachers wanted to do, what they thought they were doing in the midst of teaching, and what they actually did (Williams, 2020). As the last step, the focus was to understand how student teachers' challenges were connected to the didactic tetrahedron and aspects of knowledge in science didactics. The analytical process followed the approach of thematic analysis (Braun & Clarke, 2006), which involved describing and arranging the data in detail. The first

step of the analysis aimed at examining the student teachers' VSRs on their first and second lessons, and concerned what had captured the student teachers' attention and became the topics of their discussions. The transcriptions of the VSRs on the first and second lessons provided insight into what situations came to the student teachers' attention.

The second step of the analysis focused on identifying the challenges connected to the science content, teacher, students, and artefacts in the environment. In line with this focus, the analysis examined knowledge aspects of science didactics, such as pedagogical designs/strategies, knowledge of science content, relations to the national school science curriculum (Skolverket, 2011), experiences of science teaching – as well as knowledge about students' science understanding, and use of artefacts in the environment (Andersson, 2011; Rezat & Sträßer, 2012; Zetterqvist, 2003). This step included examining similarities and differences between the challenges with science didactics, grouping them into themes, and distinguishing the core and pattern of variation within the themes (Braun & Clarke, 2006).

Thus, the thematic analysis was both inductive (first step) and deductive (second step) in nature. In the third and final step of the analysis, the didactic tetrahedron (see Figure 1) was applied as an analytical tool to examine the character of the student teachers' challenges with science didactics. Using the tetrahedron as an analytical lens enabled us to illustrate what relationships in the tetrahedron came into play and the character of these interactions.

Limitations

The presented research can be considered a small qualitative study in a specific context, precluding generalizability on a larger scale. The video recordings of the student teachers' science lessons could not capture all the students' reactions and interactions with each other and the exhibitions environment. These circumstances limited the student teachers' access to the students' conversations, thoughts, and feelings about their experiences. Another limitation concerns the content of reflections. Since the student teachers were given the autonomy to determine when to stop the video and decide what concerns to discuss in the VSR, general pedagogical issues, and aspects of individual performances were discussed, along with aspects of science didactics. A more structured interview protocol explicitly addressing aspects of science didactics would have generated a more extensive reflection on such issues, with the risk that the reflective process is lost.

RESULTS

Four challenges with science didactics emerged through analyses of the student teachers' VSRs on their science lessons at a science centre. The influence of artefacts as representations, knowledge about school students' science understanding, making science content accessible, and the complexity of asking questions. However, the challenges do not constitute distinctly different categories due to the unique character of science didactics. The actors and aspects of the didactical situation (student teacher, student, science content, and artefacts) are closely intertwined. Accordingly, some of the excerpts presented in the results could occur in more than one challenge category. In the results, each challenge's most salient characteristics are highlighted by selecting excerpts, each demonstrating the focus of the science didactics aspects.

A complete list of the number of identified excerpts connected to the four challenge categories is presented in Table 2. In addition to each challenge's presented excerpt, the relationship and character of the interplay between the student teachers, science content, (school) students, and artefacts are illustrated by the didactic tetrahedron. In the results, the three groups of student teachers are referred to as the 'Life in space group,' 'Ecosystems group,' and the 'Evolution group.'

Table 2. The table presents an overview of challenges experienced by the three groups of student teachers.

	Life in space group	Ecosystems group	Evolution group	Total number of excerpts in each challenge category
The influence of artefacts as representations	5	4	1	10
Knowledge about school students' science understanding	3	6	3	12
Making science content accessible		8	4	12
The complexity of asking questions	4	3	2	11
Total number of excerpts in each group of student teachers	12	21	10	

The influence of artefacts as representations

One challenge that student teachers in all groups become aware of when they reflect on their teaching is the influence of the environment’s artefacts. The artefacts affect both their own and the students’ attention, sometimes directed toward and sometimes away from the planned science content. This causes conflicting intentions. The surface that comes into play is the relationship between student teachers – artefacts – science content (see Figure 2). Another challenge for the student teachers is to match the artefacts as representations with the science content’s formal curriculum documents. The influence of artefacts varies and may contribute to (as representation) or disrupt the student teacher’s planned science content.

Artefacts as disruptions

In the following excerpt from the ‘Ecosystems group’ after the VSRs on the second lesson, Stina expresses the conflict between sticking to the lesson plan and, at the same time, attending to the different organisms in the exhibition.

Stina: I would say that it takes focus away from our attention as well [the others agree]. My [call] above all, “Check out that bird! Check out that bird!”. “We’re talking about ecosystems now, shape up, Stina!” [Stina says what she was thinking then, and the others laugh]. So, a little like that.

Interviewer: Mm

Stina: But there’s a difficult balance [between] sticking to what we are going to talk about and what’s interesting in there.

The example above demonstrates how the bird (artefact) becomes a representation and disrupts the planned science teaching. As unplanned artefacts ‘enter the scene’ and draw attention, they may implicate science content other than what the student teachers initially planned. Dealing with such situations requires adaptability and responsiveness to the environment’s dynamic character and the students’ focus of attention and interest.

A mismatch between the exhibition’s artefacts and the science curriculum content

The excerpt is an example of the mismatch between the science content in the formal school curriculum for the students’ age group and the exhibition’s artefacts. Cecilia tells about how they solved the problem by taking the exhibition in the ‘Life in space’ group as their starting point.

Cecilia: Even though we found that there was more [content intended] for grade six in the knowledge requirements, it was perhaps a little higher level than what they [the knowledge requirements] said for grade three. It was about what we've read now, about astronomy, about the phases of the moon and the earth and maybe ... Well, there wasn't much [to find about this topic] in the exhibition at that time. So, I believe we started from [the exhibition], but maybe it also made it a bit, I don't know ...

The student teachers are aware of the representations' contributions. Still, they do not know how to connect them to the science described in the current age group's formal curriculum and knowledge requirements (Skolverket, 2011). The didactical situation indicates that the student teachers have difficulty arranging and utilising artefacts as representations, enabling an interplay with the planned science content. Furthermore, the student teachers and their students do not always share artefacts (as representations). Hence, in the didactical situation, the student teachers fail to get the students to interact with the artefacts in the environment. Concerning the tetrahedron (Figure 2), it becomes evident that the exhibition's multiple representations influence and shape the learning situation.

Figure 2. The dashed surface in the didactic model illustrates the relationships that come into play in the didactic tetrahedron.

Knowledge about students' science understandings

During the VSRs, the student teachers become aware of their lack of knowledge about students' understanding of science content. They experience the difficulty of teaching at a level appropriate to the students' age group. They also address expectations concerning students' experiences and interests that do not correspond to the age group. We see a variation in what the student teachers focus on in relation to students' understanding regarding this aspect of science didactics. One is that they become aware of students' understanding of the science content but do not focus on the representation integrated with this science content. The other is that they become aware of their own understanding of how the representations and science content differed from the students' understanding of the purpose of the teaching activity.

The science content and students' level of knowledge

One example of the student teachers becoming aware of their lack of knowledge about students' understanding of the science content is when Katrin from the 'Life in space' group addresses the problem of adapting the science content to the students' level of science knowledge. In the video footage, Cecilia has gathered the students around her and the exercise bike. She explains to the students how the heart and blood circulation are affected by weightlessness. Then she asks the students whether they know how the lungs are affected. The surface that comes into play is the relationship between student teachers – students – science content (see Figure 3).

Katrin: Pause. Listen, it's probably going to be a little too difficult here.

Cecilia: Yes

Katrin: Do I feel now ... a little too ... what should I say, abstract? Or it's ...

Cecilia: Absolutely. How can they know how it [what happens to the lungs in weightlessness], when they don't know how the lungs work otherwise.

Figure 3. The dashed surface illustrates the relationships that come into play in the situation, indicating the lack of interaction between students and science content.

Student teachers' preconceptions and students' experiences

In the next excerpt, the student teachers from the 'Life in space' group become aware that the students' may not have understood their assignment to learn how one lives in space. The student teachers recognize the gap between their preconceptions about the students' understanding of the planned assignment, on the one hand, and the student's actual experiences of the didactical situation, on the other. They also realize the importance of being explicit about the purposes and aims of different activities and the stories they create through teaching. The video footage shows the end of their first lesson. The group of students is gathered in the Uniview (a confined space with interactive space-imaging software, which consists of three-dimensional visualizations and simulations using astronomical data). One student teacher operates the simulator and the 'space journey' back to earth from the ISS, using a joystick. The students observe the journey as if they were passengers on the space shuttle. When landing, the student teachers are not able to land the shuttle on the ground. Instead, the space shuttle crashes into the ocean. After the ocean landing, Katrin turns to the students and asks them if they think Christer Fuglesang would be satisfied with the outcome of the assignment. One of the students answers no, which surprises the student teachers.

Cecilia: Why did they say no?

Katrin: Then I thought, well! They might not, or I got the feeling that they thought they were not allowed to do any assignment.

Cecilia: Mm

Katrin: And that's because they said no.

Interviewer: What do you others think? Why do you think he [the student] said no?

Cecilia: Either it's because he doesn't think he ... well either it was because he didn't learn that much or because he felt that "I haven't been so active so I don't know, I haven't received any document saying this was so good, I don't know ...

Sandra: The assignment was to learn how to live on a space station [the others agree]. Maybe he just said that. Maybe we weren't so clear in saying that that was the assignment.

The student teachers' surprise at the response of one of the students indicates that they focus their attention on the students' experiences of the assignment and the learning outcome. At the same time the artefacts as representations (the Uniview journey, the space shuttle's landing) in use and how they were handled, remain in the background. The student's way of answering the question implies that his attention was on the activity, the space journey back to earth, and landing in the ocean. Although the student teachers become aware of their lack of knowledge about students' understanding of science content, they do not focus on the representation integrated with this science content. The example shows that the student teachers fail to bring about the interplay between the artefacts as representations, science content, and students. The excerpt is an example of how the challenge themes are intertwined and how artefacts as representations are highly present in the didactical situation. The didactical situation is illustrated in Figure 4.

Figure 4. The dashed surfaces illustrate the relationships that come into play in this situation, demonstrating that the influence of artefacts is also present.

Making science content accessible in a teaching situation

The third aspect of science didactics concerns the student teachers' awareness of their ability to make science content accessible so as to facilitate students' understanding – in other words, having the knowledge and skills to teach specific subject content to a particular age group. Regarding this challenge, two aspects are salient. One is the problem of being inconsistent in their use of concepts, which indicates the significance of science language. Another is the uncertainty about which concept and word to use in relation to what the students understand. The results presented in this third challenge theme are closely intertwined with the second theme, *knowledge about students' understanding*. To make science content accessible, student teachers must understand how their students experience this content and what [science] language to use. That is, to use concepts and words that correspond to their students' level of knowledge. The surface that comes into play connects the student teachers – the science content – students (see Figure 3).

Relating key concepts

In the following excerpt, the student teachers in the 'Ecosystems' group become aware of how they use concepts and terms inconsistently in their teaching. In the excerpt below, Stina realizes that using different words to articulate the same thing can confuse the students. The video footage is from the sequence in which Stina instructs the students to look for consumers in the exhibit. To help the students understand what to search for, she uses different words to explain the meaning of the concept of consumers.

Stina: Can we stop? I am currently reflecting on the fact that I am very inconsistent with the use of concepts. I say organisms, I say animals, I say consumers. I haven't landed on anything. That can be very tricky, I think.

Rick: You mean you would change, "and animals that eat."

Stina: Yes, I might say it was animals, or yes ...

Rick: Yeah, right, but we discussed it before, if you were to say top predators or something like that or?

In this next excerpt, in the 'Evolution group,' Erik becomes aware of the difficulty of selecting appropriate words to explain scientific phenomena. It becomes evident how his insecurity in relation to making science content accessible concerns his lack of teaching experiences of the particular science content to the students' age group. The video footage shows Erik's teaching about the gecko's adaptations. He has gathered a small group of students by the Gecko terrarium, explaining how the gecko's feet can attach to flat surfaces.

Erik: ...what I thought about already then, but also now, are the words to use when explaining something like this. And also, square centimeters, was that what I said?

Alice: Square millimeter.

Erik: Square millimeter.

Filip: Milli, yes.

Erik: Maybe I should have explained what a square millimeter is because I don't know if they know it or not. They must have read about it in eighth grade, or whenever it was. But even these molecular forces, "molecules in them, molecules in it" [Erik quotes himself in the teaching situation]

The relationships that come into play in this theme are the same as in the *theme Knowledge about students' understandings* (see Figure 3), with a focus on science content accessibility.

The complexity of asking questions

Asking questions is part of the knowledge base in science didactics and is a prerequisite for communicating science content and engaging students in doing science. In the fourth challenge theme, the student teachers become aware of the complexity of using questions in teaching. The student teachers realize that the questions they asked did not always serve the purposes for which they were planned. One of the salient aspects is their awareness of the ability to ask questions to direct students' focus toward the science content, enabling them to reflect on the science content, and making them aware of their learning. Another aspect is the student teachers' use of questions to learn about students' experiences, the difficulty of asking the right kind of questions at the right time, and in being precise about how the question is worded.

The purpose of questions

In the following excerpt, the student teachers in the 'Life in space' group realize that if they learn about their students' experiences and enable students to become aware of their own learning, questions serve an important purpose. The video footage has just shown the end of the first lesson with their first group of students.

Cecilia: No, it was not a good ending. It didn't happen. We didn't have time for it. We had planned to ask some questions as well.

Katrin: Yes, that's right.

Cecilia: In that way, we could have gotten an idea about what they had learned, that they themselves were aware of what they had learned, and so on. We didn't have time to do that.

Questions to stimulate students' thinking

The following excerpt illustrates the importance of questions in stimulating students' thinking and helping them contextualize concepts. The student teachers also become aware of the importance of asking the right kinds of questions at the right time in a teaching situation. In the excerpt from the 'Ecosystems' group, Jesper realizes that he could have asked a specific question to focus students' thinking on linking producers in nature to the rainforest.

The video footage shows Jesper's teaching about the concept of producers and what producers do by bringing in examples of different kinds of producers the students know about (music producers, car producers, etc.). He is aiming to talk about producers in the natural world.

Jesper: Here, I think I should've actually asked [the students] that too.

Mikaela: What are you thinking about?

Stina: Plants in the rainforest.

Jesper: "When you talk about producers in the rainforest, you think of something else, does anyone have a guess? [Jesper quotes what he says in the teaching situation]"

Rick: Mm.

Jesper: I think I should've done that.

Rick: Yes.

Stina: Asked the students.

Jesper: Yes, because I think that when you've started to think about what a producer is, then maybe you can connect, "yes but the rainforest - producer," or at least come up with some guess.

On the other hand, the student teachers mention the risk of getting off track, of drifting away from the planned science content by asking too many questions.

Stina: How much should we ask the students then, how much should they [themselves] control the content compared to what we [should control]?

Jesper: No, it's hard.

Rick: Too many questions can also make them think of other things and go in the wrong direction.

Stina: Yes.

Rick: So, you lose them [the students] a little bit, in what you want to achieve.

Questions to direct students' attention

In addition to becoming aware of using questions for specific purposes in teaching, the following excerpt from the 'Life in space' group (in VSRs 1) is an example of the importance of asking the right kinds of questions at the right time in a teaching situation. Cecilia explains how she tried to ask questions to direct students' attention to the environment's representations. However, she becomes aware that her inconsistency in questioning may have confused the students. She also sees the difficulty of using theoretical knowledge derived from coursework about questions in practice. In the video footage, Cecilia is directing the students' attention to the space exhibition's different features while taking the students through one of the authentic models of the ISS interior. The module is shaped like a horizontal half-cylinder with a vaulted roof. On the walls, there are built-in TV screens that show astronauts and the earth from the ISS.

Cecilia: Yes, I was thinking of trying to bring in questions that draw [the students'] attention [to the exhibition], "Oh look here! What can you find here? What do you see?"

Katrin: Yes, you said that [you wanted] to try to get their thoughts going.

Cecilia: But maybe it also became a bit, that it rather became a bit too unstructured and that they didn't know, "What are we going to do now then? Should we watch or should we listen or something?"

/.../

Cecilia: I thought from the beginning, to get them to feel that "now we're in space." Then it was somewhat difficult: "How does it feel? How does it taste? How..? To use your senses. "How does it sound?" Because it [exhibition] has such a wonderfully roaring sound, "Is that how it sounds on a space shuttle?" something like that. But it didn't really turn out so well. It was a thought anyway.

The use of questions to direct students' attention toward artefacts (e.g., buzzing sound from space models, flying birds, and waterfalls) as representations is not only planned but something that happens as artefacts pass by or as the group of teachers and students pass the artefacts. Furthermore,

the challenge theme demonstrates that using questions to create an interplay between the students, subject content and the artefacts used in the teaching-learning situation is challenging and something they cannot yet master. The complexity of asking questions connects the student teachers with the students, the science content, and the artefacts on two surfaces. The relationships that come into play are illustrated in see Figure 4.

DISCUSSION AND IMPLICATIONS

In this study, the influence of artefacts as representations become central and contribute with knowledge about the difficulties student teachers have in arranging and utilising artefacts as representations, enabling an interplay with the planned science content and students in a didactical situation (Brousseau & Balacheff, 1997; Rezat & Sträßer, 2012). The didactic model (Nyman, 2017) foregrounds the challenges of science didactics concerning the influence of artifacts in the student teachers' didactical situations. From a teacher educator's perspective, the use of the model enables deeper knowledge of student teachers' ways of creating didactical situations where artefacts are taken into account (Rezat & Sträßer, 2012).

As teacher educators, we must provide learning experiences for student teachers that develop adaptability and responsiveness to the [unfamiliar] artefacts in the environment and make use of them as representations when creating didactical situations. Also, to present these artefacts to help students interact with them in relation to their own knowledge of the science content and the learning environment. This is in line with (Sjöström, 2018), who suggests that science didactics needs to connect to the science content, teaching practice, and educational theories. We emphasise that artefacts in material-rich science environments should be considered and as part of the teaching practice.

Other challenges that become visible when using the didactic model as an analytical tool are student teacher's knowledge about school students' understanding of science, and an awaked awareness of their ability to make science content accessible to facilitate students' understanding, and the complexity of asking questions. Although these findings concern challenges identified by student teachers in a particular context, they are in line with earlier research on student teachers' challenges of learning to teach science (Avraamidou, 2014; Harlen & Holroyd, 1997; Wickman, 2018; Zetterqvist, 2003). Thus, the study demonstrates that the didactic model is a valuable analytical tool for discerning the complex act of creating didactical situations. To the extent that the didactic model can be used as an analytical lens for research, it can provide a powerful 'thinking' tool for student teachers – as well as teacher educators in their practice (Wickman, 2018).

In addition to these challenges, the issue of integrating one's theoretical understanding (derived from course work) about science teaching into practice becomes visible (Hammerness & Klette, 2015; Jensen, Klette, & Hammerness, 2018). This is another indication that the student teachers do not yet have the ability to create a didactical situation that includes all the elements needed to enact their knowledge in action. In addition, the student teachers appear to interpret the formal curriculum too rigid and do not yet see it as a guiding framework for science teaching.

The artefact-rich and less controllable built-up environment at the science centre puts the task of creating didactical situations in a dimension beyond the more controllable classroom. We believe that these environments offer unique opportunities for teacher educators to gain a deeper understanding of student teachers' development of knowledge of science didactics in practice. A way forward in science teacher education is integrating several recurring and well-considered activities at science centres or other out-of-school science environments.

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