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University Teachers' Experiences of Teaching Hands-On Components in Science and Technology in Primary Teacher Education during COVID-19

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ABSTRACT

Teacher education programs have the dual task of teaching specific subject content while also providing examples of how this content can be taught in schools. This task is especially important, and also problematic, when it comes to technology and science education, where hands-on components such as design/construction exercises, laboratory exercises, and excursions are central epistemic practices. When COVID-19 hit, Swedish universities were forced to change from campus-based teaching to online distance education, termed "emergency remote teaching (ERT)." The present study aims to investigate university teachers' experiences of how hands-on components in science and technology education worked in the ERT mode that arose during the COVID-19 pandemic. The analysis was performed with a social semiotics and community of inquiry framework, and shows that both the type of instruction and the subject content were impacted. In particular, the reduced opportunities for students to apply scientific and technical methods and the reduced ability of teachers to determine whether the students had understood their instruction generated new ways of communicating and supporting the students' learning. Therefore, analysis of meaning making in science and technology online-learning contexts needs to address the topics of the nature of science (NOS) and the nature of technology (NOT). An extended, three-dimensional model of meaning making is suggested.

KEYWORDS

Emergency remote teaching (ERT); primary teacher education; science education; technology education

Introduction

Teacher education is different from other vocational study programs at university level because it aims to 1) teach students a subject's content and 2) teach students how to teach that content (Hartman, 2005). Teaching staff in teacher education programs thus find themselves at the intersection between teaching science content, subject-specific education (cf. *fachdidaktik*, Seel, 1999), and pedagogy (cf., Blackley et al., 2021). Their task is particularly important and problematic in technology and science education, where hands-on components such as design/construction exercises, laboratory exercises, and excursions constitute key epistemic practices. Students' involvement in such activities supports their learning of authentic scientific and technological practices and provides them with examples of how they themselves can plan their lessons (Nordlöf et al., 2022; Rudolph, 2019).

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However, this type of instruction is expensive and in recent years there has been a discussion about the use of digital solutions (e.g., Stenbom et al., 2017), which generally have not gained traction.

During the spring semester of 2020 when the global COVID-19 pandemic hit, however, Swedish universities were forced to quickly transition to distance education. This transition did not apply to online learning or blended learning courses, which were already designed to be provided as distance education (or both as distance education and on campus), but rather to campus-based courses, due to the crisis. This type of teaching is called "emergency remote teaching" or "ERT" (Hodges et al., 2020), and this article investigates university teachers' experiences of ERT, in relation to hands-on components such as laboratory exercises, excursions and design/construction exercises in science and technology in primary teacher education.

The online and blended learning research field is extensive, not only because there has been a lot of research done but also because online/blended learning occurs in many different forms (see, e.g., Lowenthal et al., 2009; Moore et al., 2011; Rasheed et al., 2020). However, the use of web-based tools to handle hands-on components in teacher education is an area of research that has so far attracted limited attention in science and technology education and related fields. From the small amount of previous research, we do know that it is important that teachers get continuing professional development and opportunities to discuss teaching and learning so that they can re-imagine hands-on subjects and how they can best be taught in online form (Burke, 2021).

There are some studies focusing on how students handled ERT during the pandemic (e.g., Blackley et al., 2021; Colthorpe & Ainscough, 2021; Salta et al., 2021). Yeşiloğlu et al. (2021) concluded that chemistry student teachers see both advantages and disadvantages of being able to participate in chemistry lab exercises in the form of filmed online experiments. Two positive aspects highlighted are being able to participate from home and being able to view the same filmed material multiple times. But many students also described uncertainty about conducting laboratory exercises themselves and felt that they had only learned "theory." A related study showed that laboratory exercises do need to be carried out on site for students to gain hands-on experience of laboratory work, but also because they need support from teachers (Gerstenhaber & Har-El, 2021).

During the pandemic, teachers struggled with the lack of experience with ERT technology and teaching online (Boltz et al., 2021). One of the few studies of how teacher educators handled ERT concluded that they quickly learned to use new interactive tools such as Zoom and YouTube in their teaching and that field work and excursions were not canceled, but were converted into another format, for example, by students filming themselves (Fackler & Sexton, 2020). However, Fackler and Sexton's study, like the other studies mentioned above, do not deal with university teachers' experiences of how hands-on components have been impacted by being done in ERT mode in the context of science and technology teacher education.

Problem formulation and aim

Because the teacher educator stages the teaching in ways that aim to inspire teacher education students in their own teaching, this could have an impact on the subject-specific education communicated to the students. The present study aims to investigate university teachers'

experiences of how hands-on components in science and technology education worked in the ERT mode that was adopted during the COVID-19 pandemic. More specifically, the paper is guided by two research questions, namely: according to the teachers, 1) what impact did the ERT mode have on the pedagogical aspects of the teaching, and 2) what impact did the ERT mode have on the taught content during the Covid-19 pandemic?

Theoretical foundations

Because this article deals with science and technology education, the central epistemological nature of these domains—nature of science (NOS), and nature of technology (NOT)—are central theoretical concerns. Furthermore, meaning making in science and technology occurs by utilizing semiotic resources, and this happens in an online context that we refer to as the "community of inquiry (CoI)."

The nature of science

Natural science rests on epistemological foundations that not only permeate curriculum components but also constitute the *raison d'être* of the sciences in themselves. NOS thus has to do with what sets the natural sciences apart from other subject areas such as religion or social science, that is, the essential nature of the natural sciences (Lederman et al., 2014; Osborne et al., 2003). Central to NOS is not only scientific inquiry that forms the basis of scientific knowledge, but also process skills such as posing hypotheses, making systematic observations, and designing experiments to investigate specific questions. NOS also includes creativity in scientific inquiry and the realization that knowledge is not static (Hansson et al., 2014). NOS entails core epistemic practices, such as laboratory work and excursions (e.g., Strippel & Sommer, 2015).

The nature of technology

Technology is notoriously difficult to define, so narrow and exclusive definitions are uncommon (Hughes, 2004), but in principle technology is about the human-built or designed world. A common philosophical framework for NOT suitable for technology education divides technology into four dimensions (cf., Meijers, 2009): volition (will), knowledge, activity, and object (Mitcham, 1994). Technology constitutes objects or systems that people (with their volition and knowledge) design, construct, and use through different activities. In contrast to the descriptive nature of scientific knowledge, technological knowledge can be both descriptive and normative; the important thing is to get technological artifacts and systems to work (Vermaas et al., 2011; de Vries, 2016). Technology education is therefore characterized by students acquiring knowledge through technological problem-solving and design activities to understand, create, manage, and evaluate technological objects and systems, in the context of humans, society, and the environment (DiGironimo, 2011; ITEA, 2007; Pleasants et al., 2019; Xu et al., 2021).

Meaning making using semiotic resources

From a social semiotic perspective (e.g., Tang et al., 2022), both materials (Frejd, 2018; Hetherington et al., 2018) and interaction (Walker & Baepler, 2018) become resources in

the process where new experiences are contrasted with previous experiences and meaning making occurs (Frejd, 2019). In this article, we use the term "semiotic resources" to describe language, gestures, materials, and other resources used in communication (Frejd, 2018; Tang et al., 2021, 2022; Van Leeuwen, 2005). Depending on the context, a measuring cylinder, a sample, a piece of Lego®, a PowerPoint presentation, and a spruce or pine can be seen as semiotic resources.

Community of inquiry

In online teaching, semiotic resources influence meaning making in a digital teaching context (e.g., Oh et al., 2018). The CoI framework (Garrison et al., 1999, 2001) suggests that meaningful online learning can be created by including three interdependent elements: *social presence*—the ability of learners to develop social relationships and identify with a community; *cognitive presence*—the ability of learners to construct (subject-specific) meaning; and *teaching presence*—the ability of teachers to design and implement teaching that directs social and cognitive processes toward meaningful learning (e.g., Bozkurt, 2019).

The CoI framework helps us understand the ERT context, in which subject-specific semiotic resources support meaning making in relation to social, cognitive, and teaching presence (Figure 1).

Context, research design, and method

Background and context of the study

Science and technology teacher education programs vary over time and between countries, depending on historical context, school system, teacher education model, and the nature of the subject content (Hallström, 2015). Overall, the Primary School Teacher Program is an academic program preparing students for a learned profession encompassing both subject matter and pedagogy knowledge (cf., Openshaw & Ball, 2008). The Swedish Primary School Teacher Program is a unified program for teachers of school grades one to three, in which the same teacher often teaches most subjects. All students in this program at the studied

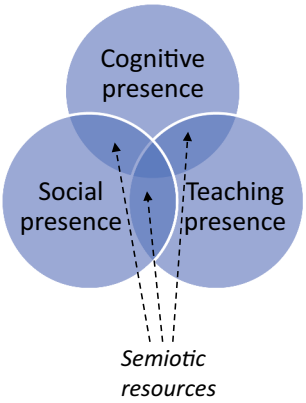

Figure 1. Semiotic resources in an ERT context as community of inquiry.

Swedish university take courses in technology and science amounting to 30 credits. The course in science is in turn divided into three smaller courses, Biology, Physics, and Chemistry, which are taught one at a time during the students' third year. During the autumn semester of 2020, most of the campus-based classes were switched to ERT (except for Chemistry), at a time when the teachers were not used to teaching online. In this article we have focused on the normally campus-based courses in Physics, Biology, and Technology.

To better discuss how the subject content of technology and science has been impacted by the ERT mode, we will first briefly describe how the courses are normally taught. In the Technology course, great emphasis is placed on the students becoming confident in teaching technology as well as giving the students a basic knowledge of the history of technology and technology in relation to humans, society, and the environment. Throughout the course, stories are highlighted as teaching tools, and the students produce their own design storyboards and test digital storytelling, as well as going on technical excursions in urban environments and doing design exercises.

In the Physics course, there are three subject blocks: Astronomy, Mechanics, and Sound and Light. A feature of the Physics course is that teachers combine traditional lectures in large lecture halls with demonstrating experiments that activate the students on the spot. For example, one teacher usually plays sounds with increasingly high frequencies and then gets the students, who are of varying ages, to sit down once they can no longer hear the sound. The last one standing often is the youngest student, which shows how hearing deteriorates with increasing age.

The Biology course has the evolution of life as its main theme. Both excursions and laboratory exercises focus on the systematics of organisms as their subject content. In the course, making observations, systematic comparisons, and field work are key elements.

In all these courses, part of the teaching takes place off campus. In the Technology and Physics courses, the students visit museums, science centers, and places in the urban environment. In the Biology course the students conduct two excursions in the natural environment. All courses also include regular academic types of instruction, such as lectures and seminars, and subject-specific methods such as laboratory exercises (Physics and Biology) and design exercises (Technology). Table 1 summarizes the types of instruction and contexts used in the courses and the subject content taught under each type of instruction.

Research design and method

After the courses were finished in November 2020, the instructors in the Biology, Physics, and Technology courses in the primary teacher education program participated in qualitative, semi-structured interviews (Brinkmann & Kvale, 2015) over Zoom (approximately 50 minutes each). The interviews focused on the teachers' discussion of the transition from campus-based teaching to ERT during the COVID-19 pandemic in the autumn of 2020. Two teachers were interviewed separately, and the other two were interviewed together because they worked jointly on both the Technology course and the Physics course.

An interview guide with three themes was developed: 1) introductory questions about their thoughts and feelings about teaching the specific course in ERT mode; 2) questions about specific course components, including, for example, questions about the challenges

Table 1. Types of instruction, contexts, and subject content in the studied courses in regular, on-campus mode.

Course	Technology	Physics	Biology
Types of instruction	Lectures Workshops Literature seminars	Interactive on-campus lectures with e.g., demonstrations of experiments Teacher-led laboratory exercises Science education seminars	Lectures Teacher-led excursions Teacher-led laboratory exercises Literature seminars
Contexts	Lecture hall, technical museum, computer room, seminar room, laboratory, urban environment.	Lecture hall, seminar room, laboratory, urban environment, two different science centers.	Lecture hall, laboratory, natural environment, seminar room.
Subject content	*Lectures*: History of technology and technological change, types of knowledge in technology, gender, and technology in relation to humans, society and the environment. *Workshops*: Digital storytelling, technology in children's fiction, history of technology, and design/construction. *Literature seminars*: central concepts and questions, based on the course literature.	*Lectures*: Astronomy, sound and light, force, motion, energy, historical perspectives on the evolution of science education. *Laboratory exercises*: Astronomy (planetary walk), sound and light, mechanics. *Literature seminars*: central concepts and questions, based on the course literature.	*Lectures*: Life, animal systematics, human anatomy and physiology, ecology *Excursions*: Nature, landscape types, fieldwork and identifying and classifying species. *Laboratory exercises*: The systematics and evolution of animals. Classifying animal species within the local environment, and specimens from other ecosystems and time periods. Comparison between different groups of animals. *Literature seminars*: central concepts and questions, based on the course literature.

and opportunities of teaching in ERT mode and questions about what was "gained" or "lost" by teaching the component in ERT mode; and 3) concluding questions about what went better than expected, the biggest challenge during the pandemic, and whether any of the changes could be made permanent.

The interviews were transcribed in their entirety and the analysis was performed on the original transcript, although examples provided in the section "Findings" were translated to English. An initial inductive coding and sorting of the material was done assisted by MAXQDA, and three main themes emerged. Coding was done at the sentence level. In other words, segments which in themselves carried meaning were coded as separate units (Hennessy et al., 2020). At this point, many segments had been coded twice and even three times. For example, the following segment was coded as both "Dynamic, human interaction lost" and "Students and teachers change their behavior":

> The structure is also important when teaching online. Because you don't see what the students look like and how they react. Rather it's a matter of really having thought ahead, I think, before you hold the lectures.

In the processing of the material, we became increasingly interested in the tension between *the content of the subject* and *the type of instruction*. All material was reviewed once again and thematically coded (cf., Braun & Clarke, 2006) to capture the teachers' reasoning regarding how the subject content of Technology, Biology, and Physics was influenced due to the context of the teaching having been changed (see Table 2). At this point, one of the single-teacher interviews was removed from the data because the teacher had not

Table 2. Summary of final themes and sub-themes, relevant examples, and involved coders.

Theme/sub-theme	Example	Coder
Consequences of ERT for the type of instruction		Author 1 and 2 jointly.
Change in interaction and dynamics	"[W]hat I lost is like seeing 'are the students with me?' [. . .] So sometimes I may have been a bit too overly explicit when I have held some lectures [online]."	Author 1 and 2 jointly.
Adaptations and new learning resources	"We have worked much more with support material on [the local learning management system]. I made a quiz to practice species, which I think was quite appreciated by them, and they used it quite a lot."	Author 1 and 2 jointly.
Consequences of ERT for the subject content of the teaching		Author 1 and 2 jointly.
Changed content in teaching Technology	"The main drawback is that you do not see others working, I think. I think it is an important lesson that you actually see what others are doing and how others are solving the problem."	Mainly Author 1, but validated by author 2.
Changed content in teaching Physics	"What I lose is some experiments. I tried here from home to run it on my balcony, why the sun is yellow and the sky is blue. It wasn't that great I would say."	Author 1 and 2 jointly.
Changed content in teaching Biology	"You can actually divide the content into two parts. One is to provide, so to speak, terminology and factual knowledge, and that can of course be done in alternative ways."	Mainly Author 2, but validated by author 1.

changed their teaching to ERT, but rather kept their course components entirely on campus. The final number of participants thus became three.

In line with ethical guidelines, the teachers were informed about the purpose of the study and that their participation could stop at any time by withdrawing their consent to participate. In addition, they were informed about how the study's data would be processed through secure storage on the university's servers, in accordance with the European Union's General Data Protection Regulation, and that the data will only be used for research purposes (Swedish Research Council [SRC], 2017). We present our findings in the next section, using pseudonyms to anonymize our participants.

Findings

The following text presents the analysis of the interviews under two main themes: consequences of ERT for the type of instruction and consequences of ERT for the subject content of the teaching. Each theme is divided into sub-themes.

Consequences of ERT for the type of instruction

This main theme describes the participants' experiences of how the transition to an online format influenced the type of instruction.

Change in interaction and dynamics

In the Technology course, Jamie would normally take the students to a technical history museum for a tour of exhibitions of military aircraft and interiors of civilian homes from different periods in history while talking about the driving forces of technology and the appearance and function of various technical objects. When this excursion was done in ERT

mode, Jamie showed images from the museum via Zoom. Here he describes how the excursion is usually done:

> Just like when you give a lecture a number of times, it's never quite the same thing every time because of course there is interaction between students and . . . er, things come up, events, there might be a sound in the background – and in this case it is usually aircraft or helicopters or something like that – that takes you off on another thread.

Jamie concluded that even though he has given the same lecture many times, it is never the same. The focus can shift very quickly when "things," such as the sound of air traffic, "come up." Jamie's reasoning is interpreted as meaning that the technical history museum as a context, with its sounds and material, influences the content because the external stimuli "take him off" on another thread. Jamie then described how the teaching turned out in the ERT mode:

> It became more, as I said, more like a lecture rather than an experience. It was flatter. There is very little discussion, conversation, and exchange of ideas. And that was partly because they were many more in number. Instead of doing this with 20 students at a time, it was, could they have been 80 or whatever number they were.

Jamie initially said that the course component became "more like a lecture rather than an experience" and that it became "flatter." This could be interpreted as meaning that Jamie wanted to do something other than to read and that he did not feel completely satisfied with less discussion and exchange of ideas. The increased number of students who participated in the online format—80 students instead of 20—could be a reason why the level of interaction changed. Later in the interview Jamie returned to talking about how the component changed in the ERT mode:

> Spontaneity just disappeared entirely because I decided beforehand that I would take up these different things and most of them require some kind of image support to talk about them. And then there is like no opportunity to discover anything . . . a question that comes up you can like . . . normally you can point it out on site – and talk about it. But here there is no way of getting there, instead you have just had to control beforehand . . . I mean everything, beforehand.

Jamie highlights that "spontaneity disappears" and that it was not possible to capture what students are asking about, because what is said was prepared beforehand and supported with selected PowerPoint images. Jamie's reasoning is interpreted as him missing the physical access to the space, the unanticipated sensory impressions, and the subject-specific material, since all these factors help make the class dynamic. In other words, Jamie's teaching presence is actualized when other materials and events become semiotic resources in ERT compared to the museum context. In the long run, the ERT mode affects the narrative—it becomes more controlled.

Charlie described similar adaptations, and his description also reflected how other semiotic resources become important in normal, on-campus teaching mode compared to when the component is taught as ERT. In the following excerpt, he talks about this in relation to how he usually teaches complementary colors and illustrates theory with experiments. The excerpt begins with the interviewer/author asking what Charlie usually does:

Author: How did you do this when it was on campus, previously so to speak?

Charlie: Well, then I stood at the whiteboard and illuminated it with a floodlight, and then I took up an A4 sheet of green paper, for example.

Author: Aha.

Charlie: And placed this on the whiteboard, and I would ask them to look at it for 30 seconds, and then I whipped it away like that and then they see the complementary color to green like that. I arranged it so that I had, at the lecture, a green color in PowerPoint at the lecture and then they were asked to look at a white surface afterward, and it worked perfectly fine, it wasn't a problem [. . .] but what I lost is like seeing "are the students with me?" You see that so well—in their eyes, posture, and such things, their smiles—if they understand or don't understand. So sometimes I may have been a bit too overly explicit when I have held some lectures [online].

Charlie described how he usually illustrates complementary colors by first shining a bright light on a green paper held against the whiteboard in the lecture hall. When the same component was to be done during a streamed lecture, the green color was shown on the students' computers and instead of looking at the white whiteboard, then they looked at a "white surface" in their home. Charlie noted that this ERT solution worked well, in that the students could see the complementary color, but the interaction with the students was different, which created difficulties with the students' social presence, in seeing whether they were "with" him. Charlie described looking at the students' body language and facial expressions to determine whether they had understood what he wanted to convey (Mavrommatis, 1997). This can be interpreted as Charlie saying that even though the experiment itself, showing complementary colors, worked well, he did not feel sure about the cognitive presence, whether the students *understood* what the purpose of the experiment was or what happened when they saw the complementary color on the white surface in their home. Because students' social presence (Oh et al., 2018) is different online, and Charlie was unable to see the students' reactions, he became "overly explicit."

Both Jamie and Charlie gave examples of how the social and the teaching presence changed in ERT mode. Jamie said that "spontaneity disappears" when what he is going to say is planned in detail instead of being shaped by the moment, and Charlie described that he becomes "overly explicit" when he does not receive the same direct feedback from the students. The dynamics and interaction with the semiotic resources of the surrounding environment thus also impact the discussions between teachers and students. The next theme focuses on how teachers have developed their teaching repertoire because of ERT.

Adaptations and new learning resources

Charlie did not use PowerPoint presentations in his lectures before the pandemic, but this became standard in his streamed lectures:

> [The PowerPoint presentations] were good, the students said, and then I said that I can post them as extra material so you can look at them as well. Because of course it also means you can do your own experiments on them, you kind of hear . . . yeah, what you hear with your ears. And you can check out complementary colors and you can check your blind spot and the like. So it's up there [on the local learning management system] actually. It's possible that I will post that as extra material next year; we will see.

When the students expressed to Charlie that they appreciated his PowerPoint presentation, he uploaded it onto the course's local learning management system, thus enabling the students to do their own "experiments," such as finding their blind spot and seeing complementary colors. Charlie also stated that it is possible that he "will post that as extra material next year."

Alex also talked about more supporting material when the campus-based lab sessions and the instructor-led excursions were not provided in the Biology course:

> We have worked much more with support material on [the local learning management system]. I made a quiz to practice species, which I think was quite appreciated by them, and they used it quite a lot. Then I could go in and see how much they . . . what they struggled with and how much they used it. It was like a way to practice knowledge of species from home.

Alex described having designed a species quiz and stated that he could see what the students "struggled with," which is interpreted as being that he was able to see which questions the students answered correctly or incorrectly in the digital form. In addition to the students being given the opportunity to "practice knowledge of species from home," the quiz thus also served to give Alex feedback on what the students were having difficulty with. Alex further stated that the support material will probably continue to be used in a normal (on-campus) mode:

> There are of course things that you want to keep [. . .] And you note that of course from the students, that they really appreciate very much all the support material they get.

As we saw in the previous sub-theme, the social presence changed with ERT mode. To handle this, the teachers created new ways to support students in their learning. By creating an online quiz, Alex was also able to compensate for the limited opportunities for student feedback, since he could see in the quiz what the students had answered correctly or got wrong.

Other examples of adaptations that recur in the interviews are that the teachers created open, online question times. Charlie described, for example, how he connected to Zoom one hour every Friday. In answer to a direct question about whether there was anything he would like to take with him from ERT mode to normal (campus) mode, Charlie replied:

Charlie: Well, that hour every Friday, it's worth a lot. And it's not especially arduous either. The only thing is that you are tied to sitting in front of the computer. But as I said, you can work with other things as well if there are no questions that come up. I'm going to keep this if there are economic possibilities in the courses.

Author: It's a bit like, I'm thinking, having your office door open.

Charlie: Yes, it is. But it's easier. They can sit at home [. . .] You also avoid the e-mails . . . that fill your mailbox, and they can also hear each other's questions. There are quite a few positive things with those Friday meetings.

The interviewer compared Charlie's online meeting every Friday with having "the office door open." Charlie agreed but said that it is easier for students to participate online because they can do it from home. He also pointed out that another positive thing about the "Friday meetings" is that he gets fewer questions via e-mail.

This theme highlights how ERT has led to a change in the social and teacher presence, how teachers have tried to manage the changed teaching situation by adding new ways to support the students, and that some new learning resources (online quizzes and PowerPoint presentations) and ways to communicate (online question times), will continue to be used.

Consequences of ERT for the subject content of the teaching

The following theme is about how the subject content in teaching science and technology has been impacted by ERT.

Changed content in teaching technology

In the interviews, the discussion around the subject content of the Technology course was mainly about changes in the students' opportunities to apply a technological problem-solving approach, which includes identifying needs, and designing and creating solutions. The Technology course usually includes a design exercise where students in small groups are required to create technical solutions to cross a lake, for example. Normally, this is done in a technology classroom where students have access to tools and construction materials in the form of wood, plastic, glue, etc. Jamie believes that this can be challenging for students when they are not in the same room:

> The main drawback is that you do not see others working, I think. I think it is an important lesson that you actually see what others are doing and how others are solving the problem . . . here you are very much alone in trying to solve a problem. And the same thing that I talked about with creativity et cetera . . . if you want to get anywhere you need to see different types of solutions; now you are just seeing "end results" (gesture) [. . .] not the process itself.

Jamie's discussion highlighted how cooperation and the opportunity to share in others' ideas are important aspects of the students' learning about technical design. He linked creativity to the opportunity to see how others solve the same problems, but also to accessing examples of different types of solutions so that, in relation to the design process, students can engage in meaning-making processes that generate ideas for a variety of solutions and then evaluate the solutions proposed (Schut et al., 2022). This is interpreted as Jamie meaning that the students, through seeing others solve similar tasks, become more creative themselves. This can be seen as an example of the social presence also influencing the cognitive presence, that is, the students' ability to make meaning about technology.

In the previous main theme, several examples were given of how Jamie adapted a course component, previously done in the form of an excursion to the technical history museum, to ERT. Here also, the subject-specific content was impacted by being done as ERT:

> And the next step that was hard was finding images [. . .] So that controlled, of course, quite a lot about . . . how I . . . how and what I could talk about. Some of the things I talked about disappeared altogether because I didn't find good pictures that showed what I wanted to talk about.

Jamie described how ERT "controlled" what he could "talk about" and he also noted that some objects—and thus parts of that dimension of technology (Mitcham, 1994)—were rationalized away because he did not find "good pictures" that he could use as semiotic resources in his teaching. In Jamie's reasoning above, it is clear that ERT influenced the choice of content that would, or rather could, be taught.

Changed content in teaching physics

In the same way as designing and constructing can be seen as a fundamental part of the subject of technology (Nordlöf et al., 2022), designing and conducting experiments is a fundamental part of science practice (de Vries, 2021). Charlie makes the following reflection on what he loses with ERT:

> What I lose is some experiments. I tried here from home to run it on my balcony, why the sun is yellow and the sky is blue. It wasn't that great I would say; I cut that. Instead, I just did a description with words there, unfortunately.

Although Charlie told us that some content worked well with the transition to ERT mode (for example, seeing your own blind spot by looking at an image in a PowerPoint presentation at home), it seems that not all experiments work as well at home. He told us that "unfortunately" he had to use a written description of why the sun looks yellow and the sky looks blue. The word "unfortunately" means that Charlie's reasoning is interpreted as meaning that when there is a change from actively doing experiments to merely reading or talking theoretically about a phenomenon, something in the nature of the subject is lost.

Changed content in teaching biology

In relation to the subject Biology, Alex gave many examples of content relating to NOS (Lederman et al., 2014) and scientific inquiry (Hansson et al., 2014). During the interview, Alex reflected that the natural sciences could be divided into two parts—theory and practice:

> You can actually divide the content into two parts. One is to provide, so to speak, terminology and factual knowledge, and that can of course be done in alternative ways [. . .] But what we also want to provide is experience of and training in observing nature. And those skills, that content in the form of the skills to do that, it does become much more difficult, almost impossible, to do at a distance, because of the direct interaction you have out in the natural environment, and we cannot replace the experience of being in the natural environment, to hold and feel things, to smell things, and so on, with a virtual experience, because there . . . it's not possible to do that. So that part of the content was perhaps lost, but we still managed a factual foundation for them and the terminology foundation as well.

Alex described teaching Biology at university as being on the one hand about factual knowledge, concepts, and terminology, but that on the other hand students must also be active and develop scientific process skills by, for example, "being in the natural environment" and using different senses when making observations. Later in the interview Alex returned to this and pointed out that the students need to "practice reading the natural environment." These aspects that relate to "reading the natural environment," are a fundamental part of scientific inquiry which can be considered to be specific to the subject of biology (Bowler, 2000). Alex noted that factual knowledge can be taught in a satisfactory manner in "alternative ways," whereas practicing scientific process skills such as making observations and experiencing the natural environment is "not possible to do" virtually. This is interpreted as meaning that Alex acknowledges that parts of the subject content of the natural sciences can be adapted to ERT, but that the cognitive presence in online Biology teaching is restricted, in that scientific inquiry requires a common physical context to a greater extent.

One way to keep the hands-on components in the Biology course was to let the students do excursions on their own. Alex told us:

> It is of course more difficult to do on your own, but it is at least a better way to go out and do it yourself than not do it at all [. . .] However, what is lost there is that when you don't have any deeper knowledge about learning to distinguish things in a context, it is very difficult to know what to look for and where to look, and it is the knowledge that the expert possesses that can guide a novice in learning to look in the right way and . . . in a way to reflect on the subject, what the important elements to look at are, and what connections are there. This is something that is difficult for the novice to do, and it very easily becomes a superficial observation when you do it unguided, so to speak. And that is, of course, what the interaction is when you are out with an expert and can also observe the expert's way of reasoning, moving, looking at things. That part is lost when you do it on your own so to speak. [. . .] And it is more difficult, I think, to guide in a structured way with written instructions. It is really this that is the difficult part in this, I think. They can learn to recognize common species, they can practice learning to look, they can . . . as we try to guide them in this, like, "look at these factors", but it is hard on their own to know what . . . well, how is this done in practice?

Alex argued in detail around the advantages and disadvantages of students doing excursions on their own without a teacher. He started out by saying that it is better for students to do the excursion on their own than not to do it at all. This is interpreted as harking back to his earlier reasoning that the experience of being in the natural environment cannot be replaced. Alex went on to describe how hard it is to know what to look for and how to look, as a novice. He described how during excursions students can observe what the teacher does, how the teacher looks at things and how the teacher moves around in the natural environment (Stolpe & Björklund, 2012) and that this provides support to the students in developing their familiarity with natural science practice. Alex emphasized that he tried to guide the students by giving them assignments ("look at these factors"), but noted that written instructions are far less useful when the teacher and the student are not out in the natural environment together.

Discussion

In meeting the objective of the study, we posed the following research questions: According to the teachers, what impact did the ERT mode have on the pedagogical aspects of the teaching, and what impact did the ERT mode have on the taught content? The findings reveal that in terms of university teachers' experiences with online learning during the pandemic, both the type of instruction and the subject content were impacted when teachers met students on the other side of a screen rather than in person in the same room or environment with access to physical artifacts intended for the instruction. Although the theoretical starting point in this article is that subject content emerges through doing epistemic practices in relation to NOS and NOT, the analysis shows a complex relationship between theory and practice. On the one hand, the teachers argued that some parts of ERT worked (more or less) painlessly, for example, students can learn concepts and facts and it is possible to replace some instructor-led experiments with students testing things at home based on instructions in a PowerPoint presentation. On the other hand, the teachers argued that the students' opportunities to practice scientific process skills and technological design are reduced when course components are altered to suit ERT. According to the teachers, ERT works less well for familiarizing the students with the subjects' central epistemic practices such as "reading the natural environment" or designing technical solutions, when there is no supporting teacher as

a guide and the students cannot see for themselves each other's solutions (Eilouti, 2009; Lederman et al., 2014; Schut et al., 2022). Thus, when the semiotic resources and the teaching presence are changed from microscopes, tools or live teachers to computer screens, it also hampers the students' cognitive presence and meaning making in relation to NOS and NOT. Similar findings on chemistry students' experiences of laboratory exercises during the pandemic have been reported, where students say that they have learned the theory, but not how to apply their knowledge in practice (Yeşiloğlu et al., 2021; cf., Gerstenhaber & Har-El, 2021). Factual knowledge or technical terms cannot, therefore, replace the fundamental epistemic practices in science and technology education.

Both science and technology are consequently closely interlinked with specific artifacts and environments as semiotic resources. In the courses that were the focus of this study, subject-specific environments are normally present as part of the teaching; for example, the Technology course visited a technical history museum, and the Biology course was partly taught in an authentic natural environment. In ERT mode, the instruction and teaching presence were altered because the contexts and artifacts that could be used as semiotic resources changed. Since the meaning students make is influenced by access to material that can be used as semiotic resources (Frejd, 2019), it can be assumed that both the subject content and the cognitive presence in the courses were impacted when the context changed. In a face-to-face situation where everyone has access to the same physical environment and the content is formed in the moment as a response to the interaction between the teachers, students, artifacts, and the context, the subject content will be different from when students sit in front of different screens and more of the teaching is planned in detail—the semiotic resources are different, which affects the teaching and social presence. For example, the content of astronomy changed when Charlie chose to describe in writing why the sky is blue and the sun is yellow, as the experiment that would normally be conducted through face-to-face interaction could not be done in ERT mode. Furthermore, Jamie described excluding some subject content in ERT mode because of limited access to authentic images of technical artifacts. In other words, Jamie's focus on providing a certain type of instruction—online teaching utilizing pictures as semiotic resources rather than conversations in a museum environment with full access to technical artifacts—influenced the content of the teaching.

During the autumn semester of 2020, teachers also experienced how students' social presence was different online (Oh et al., 2018). They could not interpret the students' body language and facial expressions in the same way as they were used to (cf., Mavrommatis, 1997), thus seeing whether they had understood what was being taught. In order to overcome this lack of feedback, and to increase options for interaction in ERT mode, social and teaching presence were created through new learning resources and ways of working, such as the species quiz and online, open weekly meetings. The teachers concluded that some of these strategies might be useful even in normal (on-campus) mode. For one of the teachers, Charlie, the ERT mode also seems to have made him more positive about the use of educational technology, which also emerged from a recent Danish study. There, distance education increased interest in thinking in new ways about teaching and learning involving new technologies (Godsk, 2021).

Data for the present study were collected in November 2020, which can be considered as rather early in the pandemic timeline. As a comparison, it is notable that the most vulnerable people in Sweden were offered COVID vaccine only in late December 2020. As the COVID pandemic continued until the Spring of 2022, both digital software, tools

and knowledge of how to teach online developed. For example, Zoom now includes more relevant emojis, digital whiteboards, and more, and teachers' knowledge of how to enhance cognitive presence has increased due to knowledge exchange projects and other resources for professional development. Maybe we would have seen that Jamie, Charlie, and Alex designed their teaching differently if we had revisited them a year later. With time, Jamie might have recorded sound from the museum, Alex might have provided a virtual field trip, and Charlie might have taken a professional development course in how to design virtual experiments. However, the data presented in this study shows a snapshot of the experiences of teachers that had not been prepared to rapidly shift lectures and activities to ERT mode at the time of the early COVID-19 pandemic.

Conclusion

The ERT mode that was in place during the COVID-19 pandemic affected both pedagogical aspects and subject content in hands-on components such as laboratory exercises, excursions and design/construction in Biology, Physics, and Technology courses in a Swedish teacher education program, according to interviewed teachers. When teachers meet students on a screen or create individual, unsupervised assignments, teachers lose some of the social presence and the hints that they often get from students regarding whether they have understood or not. Furthermore, when such individualized forms of teaching are developed, students also lack cognitive presence and cannot interact with the subject content in the same way as on campus. Thus, the hands-on components—the environment and its artifacts which are integral as semiotic resources in science and technology education—are partially lost. Consequently, when science and technology are taught in ERT mode, they become different subjects compared to when they are taught on campus; certain aspects of NOS and NOT, such as factual knowledge, are emphasized, while others, such as reading nature or collaboratively designing and building technical artifacts, are downplayed.

A three-dimensional model

In conclusion, the theoretical model used in the analysis (Figure 1) needs to be complemented by NOS and NOT that permeates science and technology education and the semiotic resources in all CoI elements, resulting in a three-dimensional model for understanding how hands-on components in the teaching of science and technology subjects were transformed in the ERT mode that arose during the COVID-19 pandemic (Figure 2).

Given the centrality of NOS and NOT in science and technology education, the elements of cognitive, social, and teaching presence are here inextricably linked to semiotic resources in the teachers' and students' environment. Thus, apart from physical materials such as tables, chairs, whiteboards, and computers, in science and technology education, with their inclusion of many hands-on curriculum components, there are also subject-specific materials related to the epistemic practices, such as animal specimens, construction materials, measuring cylinders, and microscopes. The context of this paper is online learning in ERT mode during the pandemic. This digital context is different from a physical classroom, and consequently the semiotic resources differ too. Therefore, the semiotic resources coupled with the central epistemological concerns of science and technology (NOS and NOT) make

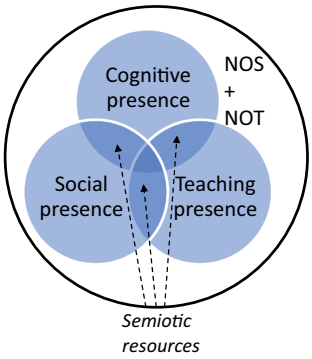

Figure 2. Meaning making of nature of science and nature of technology with semiotic resources in an online community of inquiry.

up an extended three-dimensional model of online teaching in science and technology education (see Figure 2).

Limitations

The method chosen was to conduct semi-structured interviews. The findings of the study thus show how three teachers in one teacher education program at a Swedish university adapted their teaching to online learning during COVID-19. This selection may be regarded as limited in terms of the potential for generalization. However, this is a qualitative study showing how some teachers approached science and technology education in ERT mode. As such, the study is valuable empirically because it provides examples of how teachers can manage their education of teacher candidates under certain conditions.

The convenience sample is also a possible limitation in that the interviewed teachers are also coworkers at the university and might have similar experiences of, for example, time for and knowledge about how to adjust to the ERT mode. Regarding methods for collecting data, one limitation of the study is also that we did not follow up the interviews after 2020. We might have seen other aspects of how the hands-on components in science and technology education were treated if we had interviewed the teachers in, say, November 2021 as well. Nevertheless, we still show some of the challenges teachers faced during the first phase of the pandemic. It is, however, theoretically that the study makes its most important contribution by showing what can happen to epistemic practices and cognitive presence in science and technology education when their central semiotic resources are replaced by digital ones.

Implications

There is a discussion concerning how universities should adapt to a "new normal mode" where online teaching is more dominant, and there are hopes that the experience gained during the pandemic can contribute to the development of new forms of teaching. Our study shows that instruction in ERT mode impacted the subject content that was taught. There will thus be a segment of this generation's population of teachers who will not have been exposed to the

way science and technology "should" be taught. Furthermore, in the long run, the knowledge and epistemic practices in science and technology education that student teachers develop and ultimately bring to their own classrooms will change if we use unreflected online teaching, similar to the ERT mode. The challenge ahead is to develop new digital epistemic practices and a powerful CoI, suitable for science and technology education. This may also be a call for all teachers to proactively use the current normal, on-campus teaching mode period to re-imagine hands-on subjects and how they can best be taught in online form (cf., Burke, 2021).

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References

Blackley, S., Wilson, S., Sheffield, R., Murcia, K., Brown, P., Tang, K.-S., Cooper, M., & Williams, P. J. (2021). How have Covid-19-related changes to tuition modes impacted face-to-face initial teacher education students? *Issues in Educational Research*, *31*(2), 421–439. http://www.iier.org.au/iier31/blackley.pdf

Boltz, L. O., Yadav, A., Dillman, B., & Robertson, C. (2021). Transitioning to remote learning: Lessons from supporting K□12 teachers through a MOOC. *British Journal of Educational Technology*, *52* (4), 1377–1393. https://doi.org/10.1111/bjet.13075

Bowler, P. J. (2000). *The earth encompassed: A history of the environmental sciences*. WW Norton & Company.

Bozkurt, A. (2019). Intellectual roots of distance education: A progressive knowledge domain analysis. *Distance Education*, *40*(4), 497–514. https://doi.org/10.1080/01587919.2019.1681894

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brinkmann, S., & Kvale, S. (2015). *Interviews: Learning the craft of qualitative research interviewing*. Sage.

Burke, K. (2021). "How can the creative arts possibly be taught online?" Perspectives and experiences of online educators in Australian higher education. *Asia-Pacific Journal of Teacher Education*, *49* (3), 347–361. https://doi.org/10.1080/1359866X.2020.1777531

Colthorpe, K., & Ainscough, L. (2021). Do-it-yourself physiology labs: Can hands-on laboratory classes be effectively replicated online? *Advances in Physiology Education*, *45*(1), 95–102. https://doi.org/10.1152/advan.00205.2020

de Vries, M. J. (2016). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Springer.

de Vries, M. J. (2021). Design-based learning in science and technology as integrated STEM. In I. Henze & M. J. de Vries. (Eds.), *Design-based concept learning in science and technology education* (pp. 14–24). Brill Sense Publishers. https://doi.org/10.1163/9789004450004_002

DiGironimo, N. (2011). What is technology? Investigating student conceptions about the nature of technology. *International Journal of Science Education*, *33*(10), 1337–1352. https://doi.org/10.1080/09500693.2010.495400

Eilouti, B. H. (2009). Design knowledge recycling using precedent-based analysis and synthesis models. *Design Studies*, *30*(4), 340–368. https://doi.org/10.1016/j.destud.2009.03.001

Fackler, A. K., & Sexton, C. M. (2020). Science teacher education in the time of COVID-19. *The Electronic Journal for Research in Science & Mathematics Education*, *24*(3), 5–13. https://ejrsme.icrsme.com/article/view/20403 .

Frejd, J. (2018). "If it lived here, it would die." Children's use of materials as semiotic resources in group discussions about evolution. *Journal of Research in Childhood Education*, *32*(3), 251–267.

Frejd, J. (2019). *Encountering evolution: Children's meaning-making processes in collaborative interactions*. Linköping University Electronic Press.

Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education*, *2*(2–3), 87–105. https://doi.org/10.1016/S1096-7516

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education*, *15*(1), 7–23. https://doi.org/10.1080/08923640109527071

Gerstenhaber, J. A., & Har-El, Y. (2021). Virtual biomaterials lab during COVID-19 pandemic. *Biomedical Engineering Education*, *1*(1), 1–6. https://doi.org/10.1007/s43683-020-00045-6

Godsk, M. (2021). Coronapandemiens indflydelse på universitetsadjunkters holdning til teknologi i undervisningen. *Tidsskriftet Læring og Medier (LOM)*, *14*(24). https://doi.org/10.7146/lom.v14i24.125580

Hallström, J. (2015). Drawing the boundary lines of science education: Subject associations and Swedish pre-service biology teacher education 1960-1990. *History of Education Review*, *44*(2), 219–235.

Hansson, L., Leden, L., & Pendrill, A.-M. (2014). Att arbeta med naturvetenskapens karaktär i NO-undervisningen. *LMNT-nytt*, *2*, 2–6. https://www.fysik.org/fileadmin/nrcf/fortbildning/LMNT_2014-2_NOS.pdf

Hartman, S. G. (2005). *Det pedagogiska kulturarvet: traditioner och idéer i svensk undervisningshistoria*. Natur & kultur.

Hennessy, S., Howe, C., Mercer, N., & Vrikki, M. (2020). Coding classroom dialogue: Methodological considerations for researchers. *Learning, Culture and Social Interaction*, 25. https://doi.org/10.1016/j.lcsi.2020.100404

Hetherington, L., Hardman, M., Noakes, J., & Wegerif, R. (2018). Making the case for a material-dialogic approach to science education. *Studies in Science Education*, *54*(2), 141–176. https://doi.org/10.1080/03057267.2019.1598036

Hodges, C. B., Moore, S., Lockee, B. B., Trust, T., & Bond, M. A. (2020). The difference between emergency remote teaching and online learning. *Educause Review*. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

Hughes, T. P. (2004). *Human-built world: How to think about technology and culture*. The University of Chicago Press.

ITEA. (2007). *Standards for technological literacy: Content for the study of technology*. International Technology Education Association.

Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education*, *23*(2), 285–302. https://doi.org/10.1007/s11191-012-9503-3

Lowenthal, P. R., Wilson, B., & Parrish, P. (2009 October). *Context matters: A description and typology of the online learning landscape*. AECT International Convention, Louisville, Kentucky.

Mavrommatis, Y. (1997). Understanding assessment in the classroom: Phases of the assessment process — The assessment episode. *Assessment in Education: Principles, Policy & Practice*, *4*(3), 381–400. https://doi.org/10.1080/0969594970040305

Meijers, A. (2009). General introduction. In A. Meijers (Ed.), *Philosophy of technology and engineering sciences* (Vol. 9, pp. 1–19). Elsevier.

Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy*. The University of Chicago Press.

Moore, J. L., Dickson-Deane, C., & Galyen, K. (2011). e-Learning, online learning, and distance learning environments: Are they the same? *Internet and Higher Education*, *14*(2), 129–135. https://doi.org/10.1016/j.iheduc.2010.10.001

Nordlöf, C. , Norström, P. , Höst, G. , Hallström, J. (2022). Towards a three-part heuristic framework for technology education. *International Journal of Technology and Design Education*, 32, 1583–1604. https://doi.org/10.1007/s10798-021-09664-8

Oh, C. S., Bailenson, J. N., & Welch, G. F. (2018). A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI*, *5*, 114. https://doi.org/10.3389/frobt.2018.00114

Openshaw, R., & Ball, T. (2008). New Zealand. In T. O'Donoghue & C. Whitehead (Eds.), *Teacher education in the English-speaking world: Past, present, and future* (pp. 155–171). Information Age Publishing.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas□about□science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692–720. https://doi.org/10.1002/tea.10105

Pleasants, J., Clough, M. P., Olson, J. K., & Miller, G. (2019). Fundamental issues regarding the nature of technology. *Science & Education*, *28*(3–5), 561–597. https://doi.org/10.1007/s11191-019-00056-y

Rasheed, R. A., Kamsin, A., & Abdullah, N. A. (2020). Challenges in the online component of blended learning: A systematic review. *Computers & Education*, *144*, 1–17. https://doi.org/10.1016/j.compedu.2019.103701

Rudolph, J. L. (2019). *How we teach science: What's changed, and why it matters*. Harvard University Press.

Salta, K., Paschalidou, K., Tsetseri, M., & Koulougliotis, D. (2021). Shift from a traditional to a distance learning environment during the COVID-19 pandemic. *Science & Education*, 1–30. https://doi.org/10.1007/s11191-021-00234-x

Schut, A., van Mechelen, M., Klapwijk, R. M., Gielen, M., & de Vries, M. J. (2022). Towards constructive design feedback dialogues: Guiding peer and client feedback to stimulate children's creative thinking. *International Journal of Technology and Design Education*, *32*, 99–127. https://doi.org/10.1007/s10798-020-09612-y

Seel, H. (1999). "Allgemeine Didaktik" ("General Didactics") and "Fachdidaktik" ("Subject Didactics") in Hudson, B., Buchberger, F., Kansanen, P., & Seel, H. (Eds.). *Didaktik/Fachdidaktik as science(-s) of the teaching profession? 2*(1), 13–19. TNTEE Publications.

Stenbom, S., Cleveland-Innes, M., & Hrastinski, S. (2017). Online coaching as teacher training: Using a relationship of inquiry framework. In N. Ostashewski, J. Howell, & M. Cleveland-Innes (Eds.), *Optimizing K-12 education through online and blended learning* (pp. 1–22). IGI Global.

Stolpe, K., & Björklund, L. (2012). Seeing the wood for the trees: Applying the dual-memory system model to investigate expert teachers' observational skills in natural ecological learning environments. *International Journal of Science Education*, *34*(1), 101–125. https://doi.org/10.1080/09500693.2011.561505

Strippel, C. G., & Sommer, K. (2015). Teaching nature of scientific inquiry in chemistry: How do German chemistry teachers use labwork to teach NOSI? *International Journal of Science Education*, *37*(18), 2965–2986. https://doi.org/10.1080/09500693.2015.1119330

Swedish Research Council. (2017). *Good research practice*.

Tang, K. S., Jeppsson, F., Danielsson, K., & Bergh Nestlog, E. (2022). Affordances of physical objects as a material mode of representation: A social semiotics perspective of hands-on meaning-making. *International Journal of Science Education*, 1–22. https://doi.org/10.1080/09500693.2021.2021313

Tang, K. S., Tan, A. L., & Mortimer, E. F. (2021). The multi-timescale, multi-modal and multi-perspectival aspects of classroom discourse analysis in science education. *Research in Science Education*, *51*(1), 1–11. https://doi.org/10.1007/s11165-020-09983-1

Van Leeuwen, T. (2005). *Introducing social semiotics*. Routledge.

Vermaas, P., Kroes, P., van de Poel, I., Franssen, M., & Houkes, W. (2011). *A philosophy of technology: From technical artefacts to sociotechnical systems*. Morgan & Claypool Publishers.

Walker, J., & Baepler, P. (2018). Social context matters: Predicting outcomes in formal learning environments. *Journal of Learning Spaces*, *7*(2), 1–11. https://libjournal.uncg.edu/jls/article/view/1639

Xu, M., Williams, P. J., & Gu, J. (2021). Developing an instrument for assessing technology teachers' understandings of the nature of technology. *International Journal of Technology and Design Education*, 1–19. https://doi.org/10.1007/s10798-021-09698-y

Yeşiloğlu, S. N., Gençer, S., Ekici, F., & Işik, B. (2021). Examining pre-service teachers' views about online chemistry laboratory learning experiences amid the Covid-19 pandemic. *Journal of Turkish Science Education*, *18*, 1–17. http://doi.org/10.36681/tused.2021.75