



Embracing Digital Technology in Science Classrooms—Secondary School Teachers’ Enacted Teaching and Reflections on Practice

Susanne Walan¹

Published online: 29 April 2020
© The Author(s) 2020

Abstract

The aim of this case study was to investigate what happens in science classrooms when teaching is almost entirely based on the use of digital technology. Two secondary school science teachers participated, together with their seventh grade classes. Data were collected through eight observation sessions (altogether about 9.5 h) and 9 h of interviews with the teachers. For analysis, a modified version of the Technological Pedagogical and Content Knowledge framework was used. The results showed the science teachers’ general approach in the classroom and revealed that they were self-confident in using digital technology, and utilised predetermined digital study material and, when it was felt necessary, supplemental materials. The teachers were positive about using digital technology since they thought it motivated their students and made assessment easier. The teachers claimed that digital technology had improved their teaching, providing more breadth because of access to varied digital tools; teaching had also become more individualised. Few differences were identified between different lessons, whether in physics, chemistry or biology, and unfortunately the identified relationship between the use of digital technology and content knowledge was limited. The teachers also reflected on the challenges they faced, especially in supporting low-achieving students and effectively using inquiry-based teaching through digital technology. Despite some acknowledged limitations, the study enhances our knowledge about how the Technological Pedagogical Content Knowledge framework can be used as an analytical tool in authentic teaching, with specific contexts and, above all, when education is largely based on the comprehensive use of digital technology rather than its occasional integration.

Keywords Digital technology · In-service teachers · Science · Secondary school · TPACK

Introduction¹

There is widespread interest in understanding how teaching practice is being influenced by an increasingly digitised society. Studies have presented mostly positive outcomes from

using digital technology (DT) in education (e.g. Balanskat et al. 2013; Dawson 2008; Ditzler et al. 2016; Ruthven et al. 2005): it motivates students and supports teachers in the provision of feedback and report grading. There are also reports claiming that teachers’ interest in using DT is increasing (e.g. Grunwald Associates LLC 2011).

Despite positive outcomes of using DT in education being reported, there are also critical reflections from researchers arguing that integration of DT in teaching does not automatically support learning (Cope and Kalantzis 2007); indeed, it is easy to fall into the trap of using new technology to learn old things, in old ways (Edvardsson et al. 2018; Fleischer 2013; Selwyn et al. 2017). Although many teachers have knowledge and experience in DT, this does not automatically mean that it translates into successful teaching practice (So and Kim 2009). The consensus in the studies mentioned here is that teachers use DT as a delivery medium while still retaining traditional ways of teaching.

In addition, studies have reported that teachers often do not integrate DT in their teaching (e.g. Harris et al. 2009), and the

¹ An important clarification at the outset is that when referring to DT in this study, it includes both hardware, in the form of laptops, projectors and SMART boards, and software, in the form of a platform in Google Classroom, digital study materials and other online resources. When the concept ‘digital tools’ is mentioned, it refers only to software or online resources.

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s10956-020-09828-6>) contains supplementary material, which is available to authorized users.

✉ Susanne Walan
susanne.walan@kau.se

¹ Department of Environmental and Life Sciences, of Karlstad University, Faculty of Health, Science and Technology, Karlstad University, 651 88 Karlstad, Sweden

practical implementation of digitising teaching is largely left to the individual (e.g. Tallvid 2015). Hasse (2017) argues that even though teachers have reported opportunities with using DT, they struggle because they do not have time to become sufficiently familiar with the technologies. Additionally, teachers argue that they receive few guidelines on how and why DT should be coupled with the subject matter (ibid.).

In this study, I specifically focused on how the implementation of DT shaped what was going on in science classrooms. Pringle et al. (2015) found that teachers used computers and programmes such as Word, PowerPoint and Internet browsers. However, use of science-specific software was rare and there were few teaching innovations that fostered inquiry-based science. Other researchers (e.g. Hickey et al. 2009; Hotchkiss and Dickerson 2008), however, have reported how online resources were successfully used in inquiry-based science education. It has also been reported that science teachers use DT because it can help students visualise abstract scientific phenomena and provide them with meaningful contexts (Varma et al. 2008). It has also been argued that availability to DT in the classroom is of particular interest in science teaching since this provides students with access to up-to-date science information and support learning (e. g. Traxler 2010). Science teachers use DT because of the positive outcomes that result for their students, but easy access to the technology and a positive attitude towards technology in general are also important motivational factors (Dawson 2008). Furthermore, science teachers use technology in their teaching *if* they find support for it in the curriculum and *if* they are given time to reflect on their teaching practices (e.g. Williams et al. 2004).

Even though there have been reports of successful integration of DT in science education, there are also examples of instances when implementation has not been as positive as expected (e.g. Schneider et al. 2005). In one notable example, science teachers encountered challenges when implementing DT in their teaching (Nielsen et al. 2015). Even though they were prepared and enthusiastic, they struggled with the practical use of technology and as a result, students lost interest in the lesson and instead of paying attention, they browsed the Internet and played games. The way the teachers handled the problems was to return to traditional teaching materials and methods. Although it is not explicit in this study if the teaching in science was supposed to be based on the use of DT, to my knowledge, there are no studies reporting how teachers use and reflect on the use of DT in science classrooms when teaching is *entirely DT-based* rather than DT being occasionally included as an additional element. Hence, my focus is on this particular perspective.

In many of the studies investigating teachers' use of DT, the Technological Pedagogical and Content Knowledge (TPACK) framework developed by Mishra and Koehler (2006) has been used. However, it has been argued that studies using TPACK have neglected to consider actual

implementation in authentic classroom situations (e.g. Chai et al. 2011; Willermark 2018). The focus has instead been on teachers' self-reports and development of TPACK when they are still in pre-service (Willermark 2018). Another critique of TPACK is the lack of connection to context (e.g. Pareto and Willermark 2019). In light of this, the aim in this study was to investigate how teachers reflected on their teaching in the context of authentic science lessons being almost entirely digital using TPACK as an analytical tool.

The research questions are:

How do teachers use digital technology in science classrooms?

How do teachers reflect on the use of digital technology in science classrooms?

The Theoretical Framework TPACK

Adams Becker et al. (2017) argued that:

Technology by itself is not a sufficient solution but instead an enabler of more effective teaching and learning approaches. Technology must be grounded in progressive pedagogies and models that foster greater student engagement and performance. (p. 1).

TPACK, a further development of Shulman's (1986, 1987) PCK (Pedagogical Content Knowledge) framework, has had great impact on education research. Mishra and Koehler (2006), who introduced the concept, argue that technologies can help content become more accessible to students and that digital tools enable the effective communication and processing of data. Furthermore, as DTs change, teachers' own skills must be developed.

The original TPACK framework comprises seven components: Content Knowledge (CK), Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), Technological Knowledge (TK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and Technological Pedagogical Content Knowledge (TPACK).

In an earlier study, Pringle et al. (2015) used selective parts of TPACK to code data. Separating the components was justified as they wanted to explore practices that were consistent and reliable with the data to be analysed. I also decided to use only certain parts of TPACK since technology was always included. Hence, the analytical focus was on the aspects of TPACK that include the 'T' element (see below for definitions of TPACK's 'T' components).

TK has primarily been used to understand and identify teachers' knowledge of operating systems and computer

hardware, and their ability to use standard sets of software tools (Mishra and Koehler 2006).

TPK involves understanding how teaching and learning change when a particular technology is applied. It includes pedagogical knowledge of the opportunities and limitations that come with various technical tools and how these relate in teaching practice (Mishra and Koehler 2006), i.e. which programme to use in the classroom (Koehler and Mishra 2009). TCK includes knowledge of how technology and subject content relate to each other, and how to select technologies that best embody and support particular concepts; the use of technology to illustrate or process this content is central (Mishra and Koehler 2006). TPACK includes knowledge of how technology, pedagogy and subject content interact, as well as an understanding of how technology can be strategically applied in the teaching situation. This knowledge is dynamic and thus is adaptable to the needs of different students (Mishra and Koehler 2006). In my opinion, understanding about strategic applications of technology is part of lesson planning, and hence planning is included in this concept. Furthermore, I argue, based on previous research (e.g. Magnusson et al. 1999; Gess-Newsome 2015) about the concept PCK, that assessment, knowledge about the curriculum and students' understanding are also part of TPACK.

Despite its widespread use in earlier studies, some researchers (e.g. Archambault and Barnett 2010) claim that TPACK is not clear and that separating the different domains from each other is difficult. I agree with this critique and have tried to be clear in this study how I understand the domains, based on the definitions made by the original developers of TPACK Mishra and Koehler (with the additions mentioned above). Koh et al. (2014) argue that contextual factors—such as physical/technical, cultural/institutional and intra- and inter-personal factors—which influence the integration of digital tools in teaching are neglected in TPACK. Although I do not use all of the contextual factors mentioned by Koh et al. (2014) in the analysis of data in this study, information is provided about the schools and the focus is on the specific context of science lessons. Another critique put forward is that the definition of 'T' has been imprecise (e.g. Graham 2011). I have taken this into account and therefore specified what I mean by DT with a note in the "Introduction" section.

Despite the criticisms, many researchers have found TPACK to be useful (Willermark 2018), especially its focus on integrating technology into teaching using a holistic perspective (Mishra and Koehler 2006). In a recent study, Pareto and Willermark (2019) argue for a need to investigate how TPACK can be developed within teaching practice. They analysed in-service teachers' lesson designs in different subjects in relation to TPACK. In doing so, they found a way to support teachers' TPACK development in specific situations and contexts, instead of simply addressing the general knowledge teachers need when integrating technology in teaching.

Other researchers (e.g. Harris et al. 2010; Koh et al. 2014) have also addressed the importance of connecting to context in teachers' development of TPACK. Of particular interest for this study was the approach used by Harris et al. (2010), who included planning of science lessons. This will be further referred to in the next section focusing on TPACK and science teachers.

TPACK and Science Teachers

As mentioned, most studies using TPACK are general (Willermark 2018) and not specific to teaching in, for instance, science. However, some recent studies of science teachers' development of TPACK have explored how this can be conducted using a similar approach to that used by Pareto and Willermark (2019), i.e. having teachers design learning activities, such as technology-mediated inquiry-based activities (e.g. Mustafa 2016). Harris et al. (2010) developed taxonomies of learning activities to be used, among other things, for the professional development of science teachers. They presented examples of technologies that could be used to build conceptual and procedural knowledge, as well as how to communicate scientific knowledge. There are also examples of studies using more common approaches to investigate science teachers' self-efficacy (e.g. Wright and Akgunduz 2018). Other studies integrating technology in science were mentioned in the "Introduction" section, but to my knowledge, the number of studies investigating science teachers using TPACK in the classroom is limited.

Teaching with Digital Technology in Sweden

Many Swedish teachers have stated that they need help in using DT (Swedish National Agency for Education 2016), yet many are often left on their own to develop their teaching; in these circumstances, they turn to, for example, social media to expand and share their knowledge (Lantz-Andersson et al. 2017). Whether this improvisatory approach has helped, or if there have been efforts with formal development programmes, is unclear; however, from a recent report (Swedish National Agency for Education 2019), it seems as if the situation has changed: of 2000 teachers, only a few expressed the need for professional development in basic use of DT. However, there were no examples in the report of how teachers expressed their needs when it came to using DT when teaching specific subjects.

About 30% of the teachers found that DT greatly increases students' motivation in school work and stimulates their learning. Many of the teachers (40%) at secondary school claimed that to a large extent, they have developed their teaching strategies based on the use of DT. Unfortunately, there is no specific information in the aforementioned report about how science teachers reflect on the use of DT. There has been a study where Nordic teachers were involved (Pareto and Willermark 2019), but it did not

include information about how science teachers developed their TPACK, and to my knowledge, there are no studies that explore TPACK among science teachers in Sweden. Hence, from a national perspective, this case study can serve as a pioneering first step, and it can also contribute to international knowledge about TPACK among science teachers.

Method

Research Context

In this case study (e.g. Robson 2011), two science teachers were followed in their teaching during the spring of 2018, 6 months after the implementation of digital education in the school. Conducting the study at this point avoided the inevitable first difficulties with Internet connections, logins and so on. The teachers were working in a municipality in Sweden with about 9000 inhabitants; the education board decided that teaching at the sole secondary school (grade 7–9, students aged 13–16) should be based on the use of DT from August 2017. The school is public and funded by the municipality, which like many other small municipalities in Sweden struggles economically. The decision to change to digital education was based on discussions about democracy, and the prevailing view that all students should—and could—have the same possibilities because teaching could be more individualised using digital study materials. Furthermore, it was argued that this change could motivate students because digitalisation is part of their everyday world.

The implementation of digital education meant that each student and teacher had their own digital device; the teachers were provided with laptops and the students with Chromebooks. Furthermore, all classrooms were equipped with projectors and SMART boards. Study materials were included in the devices, and a common digital platform (Google Classroom) was used with each person having their own account and access to the Internet. The digital study materials used include traditional texts found in textbooks and organised in different topics. Besides these texts, there are videos explaining and visualising different science concepts and processes. Furthermore, the content includes tasks, such as experiments, quizzes and games, the latter two providing direct feedback to the students. Many of the tasks can be performed at different levels of difficulty. In addition, the study material has built-in functions to support students with conditions such as dyslexia.

Participants

There are four science teachers at the school, which has about 300 students. Two of the four volunteered to participate in this study, together with their 7th grade classes. Both teachers had around 10 years of teaching experience: they are referred to as teacher one (T1) and two (T2).

Data Collection

I visited the classes once a month over a term and observed eight lessons, each lasting between 60 and 80 min, in total about 9.5 h. The observations were non-structured and I also took detailed field notes. The teachers were interviewed before and after the lessons, and a final interview was conducted a few weeks after the last observation (questions are in the [supplementary material](#)). In total, 17 interviews were held, lasting between 15 and 60 min, altogether some 9 h. The interviews were semi-structured, audio-recorded and transcribed. The teachers member-checked all of the field notes and agreed on their content.

Analysis

The analysis of all data was conducted by me (the author) and a fellow researcher not involved in the study, but with knowledge about TPACK. We compared our codings, and totally agreed on all of them without any differences in our interpretations of data.

We analysed data both from a self-report aspect (the interviews) and from the observations. Accordingly, the analysis could be triangulated, diminishing the risk of self-reports that could be too optimistic and describing intentions or ‘stated beliefs’ (Willermark 2018). When we analysed the field notes, we used a deductive approach, coding observations as TK, TPK, TCK or TPACK. Questions guiding the analysis are as follows:

TK: Do the teachers show any difficulties in using DT themselves?

TPK: Is the chosen DT supporting the pedagogical strategies (i.e. is it suitable in the specific teaching situation)?

TCK: Does the chosen DT support students’ learning of specific science content?

TPACK: Does the use of DT connect to knowledge about students’ understanding of the content to be learnt, and does it help assess students’ knowledge and/or connect to the curriculum?

The interviews also ended up in an inductive thematic coding as subcategories to the deductive themes. The inductive themes emerged through interpretive readings of the interview transcripts, based on thematic coding as described by Braun and Clarke (2006).

Results

Teachers’ Enactment in Digital Science Classrooms

The results of the observations are shown in overview in Table 1.

The observations showed that the teachers were technologically competent (TK). They never struggled with managing their

own laptops, the projectors or SMART boards. Some students needed support with technology, however, and above all, there was a need among some students to have texts printed (TPK), because they found it difficult to read e-texts (Table 1). The teachers often supplemented the predetermined digital study material with other materials and practical activities to support learning particular content (TCK). They used a variation of instructional strategies even though the use of DT served as the foundation. The lessons consisted of short presentations using different digital tools, individual digital-based work by the students, group discussions and practical inquiries. Throughout the observation sessions, all students were active working with different tasks relating to learning science. When the students worked individually, it was possible to conduct tasks on different levels since the digital learning material included exercises of varied difficulty. The tasks in the study material were sometimes presented as games, providing the students with points and the possibility of moving to a higher level of challenge (TPACK). The students seemed motivated to search for information about science issues related to challenges in the games and moved to other websites to gain this information. Hence, the choice of using games stimulated students' learning in science even though some students struggled with switches between websites.

Teachers' Reflections on the Use of Digital Technology in Science Classrooms

The TK Perspective

Two sub-themes emerged when this perspective was discussed: attitudes to handling technological equipment and having sufficient time to learn new programmes and prepare lessons. Both of the teachers were positive about the fact that their teaching was based on the use of DT. They did not find it difficult to handle DT, either hardware or software:

I do not find it difficult to work this way, using digital tools; it's natural. (T1)

I have always used the laptop a lot on my own, and I think it is fun that we can now have education digitally. (T2)

The teachers alluded to some initial technical problems (Internet connections that failed and so forth), but these had now been resolved:

It is critical that the Internet is working. We had some troubles in the beginning, maybe because the server was overloaded when all of the students' Chromebooks were connected. (T2)

The teachers were aware that it took time to learn how to handle different software and to search for materials to supplement the predetermined digital study material:

It takes time to learn how the new programmes work, but still it is convenient to have it in the same place and even if the preparations take time, you gain time later on by having it all gathered. It also takes time to look for material when you need to get supplements to the digital study material. (T1)

When questioned if they had been given extra time to learn how to handle the new technology, or if they had attended any courses to learn new programmes, a typical response was:

I do not have any extra time. I ask my colleagues a lot and then I look at different communities on Facebook to find advice, or in other digital platforms. (T1)

The TPK Perspective

Two sub-themes emerged when this perspective was discussed: it takes time to support the students with technological issues and it impacts on the social situation in the classroom.

It is a challenge using technology in the classroom, as the students need help with the technological issues and this takes a lot of time. We lose focus on the content because there is not enough time to help them understand. Still, I think it is positive to work this way; the students just need to learn the technology first. (T1)

Even though some students struggled with technology, they still seemed to enjoy using it. During observations, almost all students were active (and not looking at other websites than those related to the lesson); this was confirmed by the teachers:

Yes, most students appreciate this way of working, maybe because they can work at their own pace, or simply because it's more fun to work when they have their own Chromebook. (T2)

Discussing effects on the social situation in the classroom, the teachers argued:

Well, I still have tasks when they work in groups, especially in practical tasks. However, we have less group discussions nowadays. I have long lessons, so I need to have variation. The students cannot work individually in their Chromebooks all the time. We need variation, that's why I sometimes take breaks from the individual work with group discussions. (T1)

No, I do not have much group work. But, I was thinking that maybe students would be sitting all by themselves using earplugs and watching their Chromebooks. On the other hand, you may think that there are not so many social

Table 1 Summary from the observations

Content	Structure of lesson	TK	TPK	TCK	TPACK	Comments
Basic chemistry (atoms, molecules, how to write formulas)	T1 informs the students about structure of the lesson. Instructions shown on SMART board. Students work individually in Chromebooks. End of lesson, joint discussions about water.	T1 shows no signs of problems handling technology.	T1 helps students with how to use symbols in the digital programme.	All students follow the study material. No extra additions made by T1.	Students follow levels in study material individually. Assessment tasks included.	One student finds it difficult reading digital texts—prefers text-books.
Thermology	T1 informs the students about structure of the lesson. Instructions written on whiteboard. Students work with individual tasks in Chromebooks parallel with an inquiry-based activity. The students test home-made thermoses; they use Chromebooks to write reports.	As above.	Variation in activities based on the study material. The inquiry part added by T1. This includes use of digital programme to write report. No need for T1 to support students with technology.	A link to a video is added by T1 for the students to watch individually when they conduct their inquiries. The video explains thermal conductivity of different materials.	T1 has added an activity and video to further support students' learning about thermology. Assessment in individual report.	During the inquiry-based activity, students discuss results, otherwise work individually in Chromebooks.
Forces	T1 informs the students about structure of the lesson. First, they discuss different concepts related to forces in small groups. The groups are provided with concepts shown on the SMART board, followed by joint discussions. Then, they watch a video about forces, shown on the SMART board.	As above.	No need for T1 to support students with technology. The activities take place according to the study material.	Animation video added by T1 to support learning about forces. It was not included in the study material.	Different levels in the study material. The quiz is constructed like a game with different levels. Students seem to appreciate the gaming style and direct feedback.	One student finds it difficult to read digital texts. The student is offered a printed version.
Inquiry-based lesson—test of condoms.	T1 presents the inquiry to be conducted and demonstrates how an inquiry is conducted systematically by showing a video. Students work in groups. The students conduct the inquiry. End of lesson, joint discussion about results.	As above.	The students need little support with technological issues, except on how to make tables. T1 supports them.	T1 has no problems finding videos that show how to conduct inquiries systematically.	The inquiry task is added by T1 and not included in the study material. The students are supposed to send in individual reports of the inquiry as a follow-up assessment.	Practical activity. Group work, individual assessment.
Forces	T2 uses SMART board to present proficiencies the students need to achieve a following task. T2 explains the requirements by using examples and showing a YouTube video. Then, students	As above.	T2 helps one student with technological issues. All students follow the study material.	T2 adds video clip from YouTube to further explain the proficiencies.	T2 uses different strategies to inform the students about the proficiencies, both oral and visual in video clip.	Some students have difficulties reading texts in the e-book and at the same time responding to questions. The teacher

Table 1 (continued)

Content	Structure of lesson	TK	TPK	TCK	TPACK	Comments
Sex and relationships	work individually with their Chromebooks. T2 introduces the lesson by explaining the concept of gender from different perspectives. Then, joint discussions, followed by a video about a genetic defect. New video about values is shown, followed by discussions. For the rest of the lesson, students work individually with a digital tool (Mindmap) to learn different concepts related to sex and relationships.	As above.	Some students need technical support with the Mindmap application, T2 supports them.	T2 has added the videos shown, as well as the Mindmap tool. This is not part of the ordinary study material.	T2 varies videos and discussions and ends lesson with individual task. All students follow the same level.	hands out prints to support them. Students active in the discussions.
Basic chemistry (atoms, molecules, how to write formulas)	T2 presents how to make molecules in a digital tool. Presentation is made on SMART board. T2 also explains about molecules by drawing on whiteboard. The students work individually. Then, the whole class watches a video about chemical reactions, followed by a quick online test (Voto).	As above.	The digital tool about molecules is new to the students, and they need a lot of technical support.	T2 uses several digital tools to support students' learning about molecules.	T2 ends lesson by checking of students' understanding of the content by getting quick feedback using Voto (digital tool).	When the students work with study questions, T2 provides them with printed text from the e-book.
Inquiry-based lesson—test of sanitary napkins	T2 informs the students about the inquiry to be conducted. Instructions are shown using laptop and projector, followed by a YouTube video showing how to conduct systematic inquiries. The students conduct the inquiry in groups. T2 supports the students by asking questions.	As above.	The students use their Chromebooks to read instructions and to fill in a form with data from the inquiry. T2 focuses on the inquiry when supporting.	The YouTube video is added by T2. Not part of study material.	Focus on the inquiry, not on technology. Assessment will follow, students to send in individual reports on Google Classroom.	Practical activity. Use of technology to watch instruction videos and to write report for assessment. Group work, individual assessment.

interactions now when the students work individually on their devices, but there are students that usually are very quiet in the classroom and they write in the chat. (T2)

The TCK Perspective

This perspective was not covered in depth during the interviews, and no sub-themes were identified because of insufficient data. The teachers did, however, mention that it took time to look for supplementary materials. They did not explain why they sometimes needed supplemental materials and unfortunately I did not ask them about this specific issue. However, one reason that the teachers wanted supplemental materials was that they did not find enough inquiry-based activities in the teaching material and that tasks with problem-solving still needed to be developed using DT:

Well, problem-solving. This is something we need to develop. (T2)

The study material is quite good; it is only occasionally that I need to add some inquiry tasks that are not included in the material. (T1)

The TPACK Perspective

The following sub-themes relating to TPACK emerged: teachers' planning, students' understanding and assessment. Each of these will be presented as follows.

During the interviews, there were discussions about lesson planning; it was agreed that this had changed:

The students are more prepared before a lesson. They can take a look in Google Classroom and know what we are going to work with during the coming lesson since I have already uploaded the planning, what texts they are supposed to read, what tasks will be conducted, videos to watch, etc. (T2)

I plan longer in advance; I have a structure that I did not have before. (T1)

Talking to the teachers about the effects of using DT, they claimed that it had improved their teaching since they could now have more variation:

I can have more variation in the teaching; there are so many tools available. The good thing about having everything digital is that it is easier to individualise. The students can work with different tasks and at their own pace and on their level. Before, everyone was supposed to do the same thing simultaneously. (T2)

From the perspective of a student's understanding, the teachers reflected as follows:

We have some obstacles to overcome working digitally. The low achievers. First, we thought that DT would be helpful for them, but it does not work. The students have difficulties in solving assignments that require going back and forth between web pages and they often look for answers just using Google, not reading in the e-book. When they google, they end up at Wikipedia and the texts there are not adapted for teenagers. They copy and paste, without understanding what the texts are all about. (T1)

Students that needed more help previously still need it. (T2)

From an assessment perspective, both teachers were positive about how the use of DT had improved their work, not only for themselves but also for the students:

The students can, for instance, present their knowledge in different ways through quizzes or presentations or group discussions using Padlet [a digital writing area] and since I can see what the students are sending as soon as they have uploaded, I can give them direct feedback. (T2)

Assessments are so much easier to have control over now, having it all digital. The students also get the feedback much faster. (T1)

Finally, one of the teachers reflected that there were things to consider when assessing some tasks that students complete:

When it comes to assessment, there is something I need to be aware of. There are students that can make really nice digital presentations that look flashy. Then, it's easy to be cheated and forget to assess the actual content. (T2)

Summarising the teachers' reflections on the use of DT in science classrooms, both positive outcomes and inherent challenges emerge; however, the main conclusion was that it was an unequivocal good for their own teaching and for most of the students.

Discussion

Teachers' Use of Digital Technology in Science Classrooms and Their Reflections on This from a TK Perspective

Earlier studies have reported how teachers' lack of knowledge is a barrier to integrating technology in teaching (e.g. Hutchinson 2012; Koehler and Mishra 2009). In this study, it was not a question of whether to integrate technology or not, since it was

officially decided that teaching should be based on the use of DT. As witnessed during the observations and confirmed in the interviews, the two teachers participating were adept at handling technology. This finding is in line with the results presented in the report from the Swedish National Agency for Education (2019) that teachers have high self-efficacy in using DT. This is so despite the fact that implementation is largely up to the individual (Hasse 2017). The teachers in this study also claimed that they did not attend any training courses, and that it was very much up to them how they actually went about integrating DT. To some extent, they solved the problem by supporting each other, or by finding help online (as reported in earlier studies (Lantz-Andersson et al. 2017)).

Teachers' Use of Digital Technology in Science Classrooms and Their Reflections on This from a TPK Perspective

During the observations, it was evident that the teachers needed to spend time supporting students with technical issues, a fact also confirmed during the interviews. One of the things they emphasised was that some students struggled when they needed to switch between web pages (as has also been reported by Enochsson (2018)). To address this situation, the teachers printed pages from the e-book and provided students with hard copy. In doing this, they shifted from using only DT, and hence it could be argued that TPK became PK. This was the only situation identified when there was a deliberate choice to *not* use technology for some students.

Another finding from the TPK perspective was that the students seemed to appreciate having science lessons based on the use of technology. The teachers had no problems catching their attention. The teachers claimed that the reason for this positive outcome could be that often the students were able to work at their own pace with different tasks (as argued by Ruthven et al. (2005)) and on different levels. Hence, the teaching was more individualised. Furthermore, the digital study material included game-like quizzes, much appreciated by the students (as was clearly evident during the observations). The fact that students seemed to be motivated and were active could be explained by the teaching being digital (e.g. Heinrich 2012; Warschauer and Ames 2010). Furthermore, the teachers only spent the first part of the lessons on introductions; the rest of the time was free for students to work on different tasks. Even though the teachers did not explicitly express that their teaching was now more student-centred, they did claim that their teaching had changed. And as already mentioned, Ifenthaler and Schweinbenz (2016) argued that the use of DT can lead to more student-centred learning.

Both the observations and the interviews showed that the teaching varied from highly individualised to group work. However, the overall impression—and without claiming this was better—was that more time was spent on individual

teaching. Hasse (2017) found that social relations were changed when technology was used in teaching. However, even if it was noticed here that teaching was now more individualised compared with earlier, the social interactions were not studied in depth. This aspect could be explored further in a future study to investigate how social interactions might affect the ways in which teachers develop their pedagogy.

Teachers' Use of Digital Technology in Science Classrooms and Their Reflections on This from a TCK Perspective

It has been argued that when science teachers use technology, they use traditional hardware and software and not much science-specific software (Pringle et al. 2015). In this study, the school did have access to digital study materials designed for use in science teaching. However, sometimes the teachers needed to use supplementary material to further support students' learning and help them to visualise different concepts (Varma et al. 2008). The teachers' reflections and actions on the use of DT did not show much variation whether they were teaching topics related to physics, chemistry or biology. In most cases, the teachers' reflections were general, except for the need that was expressed for more tools to support learning in inquiry-based activities (which did not seem to be included in the predetermined study material). The teachers' feeling that they lacked digital material to support inquiry-based activities was in line with arguments made by Pringle et al. (2015). The teachers were not explicit about how science is created, but the inquiry-based activities covered these aspects of learning as well as science concepts and processes.

Teachers' Use of Digital Technology in Science Classrooms and Their Reflections on This from a TPACK Perspective

Both of the teachers found that their teaching had changed since they started to work with DT. They had hoped that this would be particularly good for low-achieving students; however, they were disappointed since these students still had difficulties. This finding is not in line with the report from the Swedish National Agency of Education (2019), which suggested that the use of DT would support students with special needs. However, the teachers insisted that most students appreciated this way of working and were motivated—an assertion confirmed during the observations and in earlier research (e.g. Ruthven et al. 2005). One of the changes that seemed most appreciated by the teachers (and the students) was how assessments had changed and become more varied. The teachers were particularly positive about providing students with direct feedback (Ditzler et al. 2016) and having everything gathered together, which enhanced the work with grading (ibid.).

Limitations

One of the study's limitations is that it only reports on how two science teachers enact and reflect on teaching based on DT. Another limitation is that few data were related to TCK. A reason for this was that the digital study materials were not discussed enough. Furthermore, since I studied teachers' use of DT in science lessons with different topics, I did gain a broad overview. However, following the same topic through several lessons could result in deeper insights related to the content and use of DT.

Conclusions

This study sought to obtain insight into practicalities and reflections on teaching in science when it was almost entirely based on the use of DT. The two teachers who participated were positive about DT and argued that it had improved their teaching in science, provided them with more variation in tools to use, enabled better planning and led to easier to assess and more individualised teaching; they also said that their students were highly motivated during their DT-based lessons. From the TCK perspective, there were no differences depending on whether lessons were in different science subjects. The only reflection captured that the teachers found problematic was the connection between DT and inquiry-based activities; this way of teaching did not help the low-achieving students. The study serves as a significant contribution in terms of using TPACK when analysing authentic teaching situations and above all, when teaching in science is based on the extensive use of DT and not occasionally added. As DT will surely be used more and more in teaching in the future—in science as well as in other subjects—questions of the appropriateness of its inclusion in the classroom are likely to fade and other questions will be raised. But for the moment, at least fundamental questions remain about why and how DT should be used when teaching science.

Funding information Open access funding provided by Karlstad University.

Compliance with Ethical Standards

Conflict of Interest The author declares that she has no conflicts of interest.

Ethical and Consent Statements All procedures performed with human subjects were in accordance with the ethical standards of the Swedish Research Council (SCR). Informed consent was obtained from all participants in the study, as stipulated by the SCR.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the

source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Adams Becker, S., Cummins, M., Freeman, A., & Rose, K. (2017). 2017 NMC technology outlook for Nordic Schools: a horizon regional report. Austin, Texas: The New Media Consortium.
- Archambault, L. M., & Barnett, J. H. (2010). Revisiting technological content knowledge: exploring the TPACK framework. *Computers in Education*, 55(4), 1656–1622.
- Balanskat, A., Bannister, D., Hertz, B., Sigillò, E., Vourikari, R., Kamylyis, P., & Punie, Y. (2013). *Overview and analysis of 1:1 learning initiatives in Europe. JRC Scientific and Policy Reports*.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- Chai, C. S., Koh, J. H. L., Tsai, C.-C., & Tan, L. L. W. (2011). Modeling primary school pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) for meaningful learning with information and communication technology (ICT). *Computers in Education*, 57(1), 1184–1193.
- Cope, W., & Kalantzis, M. (2007). New media, new learning. *The International Journal of Learning: Annual Review*, 14(1), 75–80.
- Dawson, V. (2008). Use of information communication technology by early career science teachers in Western Australia. *International Journal of Science Education*, 30(2), 203–219.
- Ditzler, C., Eunsook Hong, E., & Strudler, N. (2016). How tablets are utilized in the classroom. *Journal of Research on Technology in Education*, 48(3), 181–193.
- Edvardsson, J., Godhe, A.-L., & Magnusson, P. (2018). Digitalisering, literacy och multimodalitet. Lund: Studentlitteratur AB.
- Enochsson, A. (2018). Teenage pupils' searching for information on the Internet. In: *Proceedings of ISIC, The Information Behaviour Conference, Krakow, Poland, 9–11 October: Part 2. Information Research*, 24(1), paper isic1822. Retrieved from Accessed 28 April 2020 <http://InformationR.net/ir/24-1/isic2018/isic1822.html>.
- Fleischer, H. (2013). En elev – en dator: kunskapsbildnings kvalitet och villkor i den datoriserade skolan. Doctoral thesis. Jönköping, Högskolan Jönköping.
- Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education* (pp. 28–42). New York: Routledge.
- Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, 57(3), 1953–1960.
- Grunwald Associates LLC (2011). *Deepening connections: teachers increasingly rely on media and technology*. Retrieved from Accessed 28 April, 2020 <http://www.grunwald.com/index.php>.
- Harris, J. B., Mishra, P., & Koehler, M. (2009). Teachers' technological pedagogical content knowledge and learning activity types. *Journal of Research on Technology in Education*, 41(4), 393–416. <https://doi.org/10.1080/15391523.2009.10782536>.
- Harris, J. B., Hofer, M. J., Schmidt, D. A., Blanchard, M. R., Grandgenett, N., & Van Olphen, M. (2010). Grounded technology integration: instructional planning using curriculum-based activity type taxonomies. *Journal of Technology and Teacher Education*, 18(4), 573–605.

- Hasse, C. (2017). Technology literacy for teachers. *Oxford Review of Education*, 43(3), 365–378.
- Heinrich, P. (2012). *The iPad as a tool for education: a study of the introduction of iPads at Longfield Academy*. Kent. Naace Report by 9ine Consulting.
- Hickey, D. T., Ingram-Goble, A. A., & Jameson, E. M. (2009). Designing assessments and assessing design in virtual educational environments. *Journal of Science Education and Technology*, 18(2), 187–208.
- Hotchkiss, R., & Dickerson, D. (2008). A remote-sensing mission. *Science and Children*, 45(5), 44–49.
- Hutchinson, A. (2012). Literacy teachers' perceptions of professional development that increases integration of technology into literacy instruction. *Technology, Pedagogy and Education*, 21(1), 37–56.
- Ifenthaler, D., & Schweinbenz, V. (2016). Students' acceptance of tablet PCs in the classroom. *Journal of Research on Technology in Education*, 48(4), 306–321.
- Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60–70.
- Koh, J. H. L., Chai, C. S., & Tay, L. Y. (2014). TPACK-in-action: unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK). *Computers in Education*, 78, 20–29.
- Lantz-Andersson, A., Peterson, L., Hillman, T., Lundin, M., & Rensfeldt, A. B. (2017). Sharing repertoires in a teacher professional Facebook group. *Learning, Culture and Social Interaction*, 100(15), 44–55.
- Magnusson, S., Krajcik, L., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Dordrecht, Netherlands: Kluwer.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for integrating technology in teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Mustafa, M. M. E. (2016). “The Impact Of Science Teachers' Metacognition On Their Planning Choice Of Technology-Mediated Inquiry-Based Activities”. Retrieved from <https://ruor.uottawa.ca/handle/10393/35229>. Accessed 28 April, 2020.
- Nielsen, W., Miller, K. A., & Hoban, G. (2015). Science teachers' response to the digital education revolution. *Journal of Science Education and Technology*, 24(4), 417–431.
- Pareto, L., & Willermark, L. (2019). TPACK in situ: a design-based approach supporting professional development in practice. *Journal of Educational Computing Research*, 57(5), 1186–1226.
- Pringle, R. M., Dawson, K., & Ritzhaupt, A. D. (2015). Integrating science and technology: using technological pedagogical content knowledge as a framework to study the practices of science teachers. *Journal of Science Education and Technology*, 24(5), 648–662.
- Robson, C. (2011). *Real world research* (3rd ed.). West Sussex: Wiley.
- Ruthven, K., Hennessy, S., & Deaney, R. (2005). Incorporating internet resources into classroom practice: pedagogical perspectives and strategies of secondary-school subject teachers. *Computers in Education*, 44(1), 1–34.
- Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: the range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching*, 42(3), 283–312.
- Selwyn, N., Nemorin, S., Bulfin, S., & Johnson, N. F. (2017). Left to their own devices: the everyday realities of one-to-one classrooms. *Oxford Review of Education*, 43(3), 289–310.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Research*, 15(2), 4–14.
- Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, 57(1), 1–22.
- So, H.-J., & Kim, B. (2009). Learning about problem-based learning: student teachers integrating technology, pedagogy and content knowledge. *Australasian Journal of Educational Technology*, 25(1), 101–116.
- Swedish National Agency for Education (2016). IT-användning och IT-kompetens i skolan. Skolverkets uppföljning 2015. Retrieved from Accessed 28 April 2020 <https://www.skolverket.se/getFile?file=3617>.
- Swedish National Agency for Education. (2019). *Digital kompetens i förskola, skola och vuxenutbildning. Skolverkets uppföljning av den nationella digitaliseringsstrategin för skolväsendet 2018*. Stockholm: Skolverket.
- Tallvid, M. (2015). *1:1 i klassrummet: analyser av en pedagogisk praktik i förändring. Doctoral thesis*. Göteborg: Göteborgs universitet.
- Traxler, J. (2010). Students and mobile devices. *Research in Learning Technology*, 18(2), 149–160.
- Varma, K., Husic, F., & Linn, M. C. (2008). Targeted support for using technology-enhanced science inquiry modules. *Journal of Science Education and Technology*, 17(4), 341–356.
- Warschauer, M., & Ames, M. (2010). Can one laptop per child save the world's poor? *Journal of International Affairs*, 64 (*Innovating for Development*), 35–51.
- Willermark, S. (2018). Technological pedagogical and content knowledge: a review of empirical studies published from 2011 to 2016. *Journal of Educational Computing Research*, 56(3), 315–343.
- Williams, M., Linn, M. C., Ammon, P., & Gearhart, M. (2004). Learning to teach science in a technology-based environment: a case study. *Journal of Science Education and Technology*, 13(2), 189–206.
- Wright, B., & Akgunduz, D. (2018). The relationship between technological pedagogical content knowledge (TPACK) self-efficacy belief levels and the usage of Web 2.0 applications of pre-service science teachers. *World Journal on Educational Technology: Current Issues*, 10(1), 70–87.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.