

Design for learning – involving teachers in digital didactic design (D³)

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Abstract

Purpose – This study aims to investigate how primary teachers, when taking part in digital didactic design (D³) workshops at the Digital Laboratory Centre at the university, develop their insights about how digital tools can be designed and further used in their teaching of science. The research question addresses how D³ can be used to develop primary teachers' knowledge about teaching science with digital technologies.

Design/methodology/approach – During two semesters, 14 primary science teachers from three different schools participated in an in-service course at the university. Five D³ workshops lasting 4 h each were conducted with the aim to analyze, design and implement digital tools based on the needs of teachers and students. This includes discussions about the technological, pedagogical and content knowledge (TPACK) framework and further recommendations about how to choose, design, implement and evaluate digital tools for different teaching and learning situations. In between the workshops, the teachers were told to reflect on their experiences with colleagues and students and share their ideas and reflections to support collegial learning.

Findings – The results indicate that D³ has an opportunity to promote deep learning experiences with a framework that encourages teachers and researchers to study, explore and analyze the applied designs-in-practice, where teachers take part in the design process. This study further indicates that having teachers explicitly articulate their reasoning about designing digital applications to engage students' learning that seems important for exploring the types of knowledge used in these design practices and reflecting on aspects of their teaching with digital technologies likely to influence their TPACK.

Research limitations/implications – This research indicates that the increasing prevalence of information communication technology offers challenges and opportunities to the teaching and learning of science and to the scientific practice teachers might encounter. It offers solutions by investigating how primary teachers can design their own digital technology to meet students' science learning needs. One limitation might be that the group of 14 teachers cannot be generalized to represent all teachers. However, this study gives implications for how to work with and for teachers to develop their knowledge of digital technologies in teaching.

Practical implications – As this project shows teachers can take an active part in the digital school development and as such become producer of knowledge and ideas and not only become consumers in the jungle of technical applications that are implemented on a school level. Therefore, it might well be argued that in science teaching, paying more careful attention to how teachers and researchers work together in collaborative settings, offers one way of better valuing science teachers' professional knowledge of practice. As such, an implication is that digital applications are not made “for” teachers but instead “with” and “by” teachers.



Social implications – The society puts high demands on teachers' knowledge and competencies to integrate digital technologies into their daily practices. Building on teachers' own needs and concerns, this project addresses the challenge for teachers as a community to be better prepared for and meet the societal challenge that digitalization means for schools.

Originality/value – Across the field of science education, knowledge about the relation between teachers' use of digital technology and how it might (or might not) promote students' learning offers access to ideas of how to design and implement teacher professional development programs. This offers enhanced communication opportunities between schools and universities regarding school facilities and expectations of technology to improve teachers' experiences with integrating technology into their learning and teaching. This pragmatic approach to research creates theory and interventions that serve school practice but also produces challenges for design-based researchers.

Keywords Learning methods, Teaching methods, Higher education, Experiential learning, Digital learning

Paper type Research paper

Introduction

During the past decades, digital technologies have become more and more integrated into classrooms. As a consequence, internal and external expectations on teachers' pedagogical practices put high demands on teachers' competencies in using technology in their everyday teaching (Livingstone, 2012). In 2017, The Swedish Government decided on a national strategy for digitalization to be implemented during 2019–2022 in all Swedish schools and preschools. Given this scenario, teachers have an important role to play in helping students to acquire the necessary skills to become digitally competent. However, an increasing number of research studies indicates that despite increased access and improved technical artefacts, few teachers have integrated information communication technology (ICT) into their teaching in ways that lead to significant changes in classroom practices (Livingstone, 2012; Player-Koro, 2012; Hartman *et al.*, 2019). Studies of technology-mediated teaching demonstrate opportunities to provide more varied, collaborative and individualized learning opportunities (Harper and Milman, 2016) based on relevant goals which make students experience the teaching as meaningful and motivating. However, teachers need to be able to adapt to quickly changing technology and be open to technology-rich teaching and learning environments. Most teachers do not have the adequate knowledge, skills and confidence to effectively or efficiently use the available technologies to support technology integration into the learning environment (Hartman *et al.*, 2019). However, strategies of providing in-service training that only focuses on how to “handle the technology” will not support the need for a more wide-spread and pedagogically significant use of technology by teachers (Callaghan and Reich, 2018).

Inspired by a strand of research exploring participatory design approaches that support teacher's professional development (Cober *et al.*, 2015; Kelly *et al.*, 2019; Bolmsten and Manuel, 2020), we introduce digital didactic design (D³) as an activity for primary science teachers to develop their knowledge of technology by acting as designers of digital technologies during an in-service course. The premise for D³ is that if teachers take an active part in designing digital technologies on the basis of their own teaching and students' learning needs, they also become more knowledgeable and motivated to use and implement these tools into their teaching practice. The main design rationale for D³ is based on a bottom-up approach, where the actual experts on teaching and learning, the teachers are designing their own digital technologies. User involvement in digital design and development is considered to contribute positively to applications that leverage user value. However, the process of involving the user needs to be carefully considered and organized to

be successful (Bano and Zowghi, 2015). Mor and Winters (2007) argue for the need to explore participatory design processes, where teachers and technology developers co-design digital learning technologies. Empirical research about participatory design processes provides some insights concerning teachers' learnings and professional development regarding technology-mediated learning environments (Cober *et al.*, 2015; Bolmsten and Manuel, 2020). However, even if contemporary research indicates that participatory design processes can create mutual learnings and empower teachers, there are several calls for research. Bolmsten and Manuel (2020) argue that there is a need for a better understanding of how the involvement of teachers in digital design processes can help build educational capacity. McKenney *et al.* (2015) call for more research on how teachers can be involved in participatory design to create and implement high-quality digital technologies that support teachers' competence and students' learnings. Furthermore, Cober *et al.* (2015) ask for continued investigations of the conditions that lead to profitable and beneficial outcomes of teachers' involvement in digital design processes.

Mishra and Koehler (2006) argued that to be able to integrate technology into teaching, teachers need to comprehend the dynamic and transactional relationship between the technology, the pedagogy and the subject content, expressed as technological, pedagogical and content knowledge (TPACK). Good teaching with technology involves a balanced combination of TPACK.

This paper explores how D^3 can be used successfully to provide value for teachers (and students) in terms of learning opportunities. The teachers were introduced to the TPACK framework to provide a focus on not only the technology being used but the use of technology to promote students' learning of a specific content. We investigate how 14 primary teachers, while participating in D^3 workshops, design digital technologies in the shape of applications (apps) to meet students' science learning needs. In doing so, we address the challenge of developing teachers' digital competences while also developing new strategies for teaching and learning that use the affordances of the technology (Kozma, 2003).

The TPACK framework stresses the importance of formulating teacher competence as an integration of pedagogical, content and technical knowledge. As such, the TPACK framework is useful for teachers' pedagogical use of digital technologies for a particular student group's learning of a specific content. In our analysis, we investigate how primary teachers, when taking part in D^3 workshops at the university, develop their insights about how digital technologies can be designed and further used in their teaching of science. The research question that pertains the study is:

RQ1. How can Digital Didactic Design (D^3) be used to develop primary teachers' knowledge about teaching science with digital technologies?

By studying practices, where apps are developed and designed by the teachers themselves, we acknowledge the potential of technology to significantly facilitate teaching and learning. As such, the results of the study can contribute to a wider understanding of how D^3 can promote teachers' TPACK and (consequently) teaching and students' learning of science.

Technological, pedagogical and content knowledge

Thirty years ago, when Shulman (1986, 1987) introduced the term pedagogical content knowledge (PCK) to draw attention to the value of the special amalgam of content knowledge and knowledge of general pedagogy that corresponds to the professional responsibilities of teachers, issues surrounding the use of technologies in schooling were not

as significant as they are today. [Chittleborough \(2014\)](#) describes examples of ICT resources often used in science teaching:

He further emphasizes that the technological knowledge of teachers must change rapidly in response to the increased availability and mobility of hardware, software and applications and the increased digital expertise of many learners ([Chittleborough, 2014](#)). Using digital technologies in teaching might bring with it the risk of mis-using technology or not using technology in a pedagogically effective way. Further, personal use of technology does not easily translate into a productive integration of technology into teaching and learning. Therefore, TPACK becomes useful as a way of expressing and thinking of teachers' knowledge and offers a holistic perspective on technology integration into education ([Roblyer and Doering, 2010](#)).

The conception of TPACK adds technological knowledge as a new element that has to blend in with domain and pedagogical knowledge to productively integrate ICT in instructional practices ([Voogt and McKenney, 2017](#)). As such, TPACK becomes useful as a way to help teachers to express and reflect on specific teacher knowledge in different contexts, which gives a holistic perspective on technology integration into education ([Roblyer and Doering, 2010](#)).

Knowledge of content refers to specific topics such as knowledge of trees and plants or knowledge of human body, etc. Knowledge of pedagogy encompasses teaching and learning

Hardware	Software	Online
Laptops	PowerPoint, Word	E-mails
Tablets	Edit images/video	Blogs
Portable devises	Wiki, Inspiration	Wikis
Interactive whiteboard	Animation-software	Internet sites
Computer	Slowmation	You-Tube clips
Camera	Software for the	Social book-marking
Internet	Dataloggers	Search engines
I-phone	E-mail	
Scanner		
Voice recorder		
Data-loggers		
Digital microscope		

Table 1. Examples of information communication technology (ICT) resources often used in science teaching

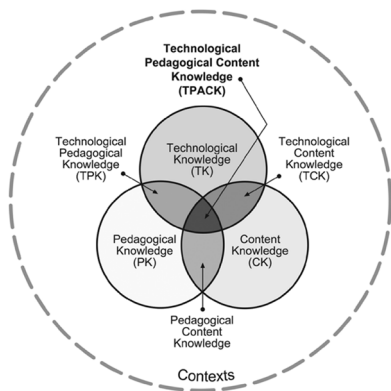


Figure 1. TPACK ([Mishra and Koehler, 2006](#))

demands in the choice of teaching approaches. For example, it acknowledges learners' different needs. Knowledge of technology refers to the resources, for example digital text or hardware, available and appropriate to be used for teaching and learning. Technology is a distinct knowledge area including the rapid expansion of digital technologies in teaching and the growing range of features of digital technologies. The technological knowledge area is rapidly evolving because of changing nature of hardware, software, applications and the mobility of devices, and in such way, knowledge of technology must never be static. The interactions between the domain of pedagogy, content and technology form another four domains: technological content knowledge (TCK), which refers to knowledge of subject matter, as it relates to the use of technology in representing it, PCK, which refers to the teaching strategies knowledge with respect to the content of the subject matter; technological pedagogical knowledge (TPK), which refers to the use of technology in implementing teaching strategies and TPACK, which refers to the integration of technology in teaching strategies to teach different subjects.

Since its introduction, TPACK has been used as a conceptual framework to understand the complex relationships between technology, pedagogy and content knowledge. Researchers (Anderson and Barham, 2013; Koh, Chai and Tay, 2014) have used TPACK as a framework to describe teachers' knowledge for the integration of ICT into their teaching. More recently, in their study of adapting the TPACK framework (see below) for online teaching within higher education, Ouyang and Scharber (2018):

Stress that understanding the synergies between content, pedagogy and technology and mastering ways to use these knowledges in creative, dynamic and open ways within online teaching are vital in supporting meaningful, technology-enhanced learning (p. 34).

Science teachers might know which digital technologies to use to support students' learning; however, they lack the knowledge and skills to design digital teaching activities based on students' learning needs (Jen *et al.*, 2015). One example of the integration between technology, content and pedagogy is through the use of simulations. Sarabando *et al.* (2014) indicated that students developed their conceptual understanding of science when the teacher used computer simulation when teaching about mass and weight. However, the positive result depended on how the teacher used simulations and not only the use *per se*.

Teacher and student use of information communication technology

At a time when ICT is ubiquitous in society, it is necessary to consider what this might mean for the perception of science education and the conditions for students' learning of science. Yeh *et al.* (2014) indicated that the rich online information that teachers can retrieve through ICT is experienced as an advantage not only for updating content knowledge (CK), but also for being used to provide students with different levels of background knowledge. A focus on scientific literacy indicates a science curriculum that has changed toward matching the new aims of science education where ICT plays an important role. Although there are changes in the views of the nature of science in primary school, the increasing prevalence of ICT also offers challenges and opportunities to the teaching and learning of science and to the models of scientific practices teachers and learners might encounter.

In recent years, some researchers have specifically addressed the role of digital applications as educational tools in different areas of knowledge (Hirsh-Pasek *et al.*, 2015; Roblyer and Doering, 2010). As a consequence, the research indicates a need for better understanding of teachers' use of digital technologies and what opportunities and challenges in terms of students' learning of science are provided. Participatory design is a way to facilitate mutual learning between stakeholders, such as educational and technical

experts participating in the design and development of technology-mediated learning environments (Mor and Winters, 2007; Bolmsten and Manuel, 2020). Inspired by the seminal work of Bodker *et al.* (2009), we define participatory design as a process where teachers take on the role of both users and designers of technology to help co-create digital learning technologies that make sense and create value for themselves and their students. Technology developers' primary role is to help set the technological framework, which forms the foundation for feasible solutions. Researchers help facilitate the participatory design process and guide the design and development of the digital technologies with the participants toward pedagogically sound implementations.

Research design and collection of data

By taking part in our D³ process, teachers were offered new ways of approaching digital technologies in their science teaching and learning practices. During two semesters, 14 primary science teachers from three different schools participated in an in-service course at the university. The teachers were in the age between 30 and 50 years and had a teaching experience between about 5 and 25 years. To select the schools, an invitation was sent to the school management to ask if there were any teachers in primary science that wanted to participate. The teachers were informed that their participation in the workshops should be documented to form the basis of a research project. The teachers also had some compensation in time from the school to be able to participate.

In the project, we carried out empirical studies involving interviews together with teachers. In other words, data collected and analyzed within the project contains personal information. The handling of this data follows the ethical guidelines of scientific research, and we have followed the guideline set by the Ethical Review Authority. All 14 teachers gave their consent to participate in the project and agreed on the audio documented workshops and interviews and the handling of data, such as transcribing and categorizing have been anonymized. In all presentation of data, the identity of the informants and of the investigated settings are anonymous.

During one semester, five D³ workshops lasting 4 h each were conducted with the aim to analyze, design and implement digital technologies based on the needs of teachers and students. This included a careful discussion about the TPACK framework and further recommendations about how to choose, combine, design, implement and evaluate digital technologies for different teaching and learning situations. In between the workshops, the teachers were told to reflect on their experiences with colleagues and students and to share their ideas and reflections on a Trello-board (online platform for asynchronous collaboration). As the D³ workshops were planned to offer opportunities for teachers to interact with researchers in science education and information systems, the researchers conducting the workshops also interacted with the teachers on the Trello-board. As such, participation in the D³ workshops enabled the development of teachers as collaborative designers and evaluators of technology-mediated teaching and learning experiences.

The D³ workshops were based on ideas of design-based research (Cobb *et al.*, 2003) and participatory design (Cooper *et al.*, 2007; Bodker *et al.*, 2009). One important aspect of the latter is the mutual knowledge creation that occurs when different stakeholders such as researchers, designers, organizations and end users envision new ideas and design collaboratively. Participatory design also empowers users by involving them in the development processes (Greenbaum and Kyng, 1991; Bodker *et al.*, 2009). Based on these ideas, the D³ workshops were facilitated to enable teachers, together with the researchers, to create digital technologies mediating teaching and learning of science. When the teachers were engaged with designing digital technologies, this provided a means to identify the

challenges and possibilities to integrate pedagogical, content and technical knowledge into TPACK.

Cobb *et al.* (2003) suggests that design-based research is carried out in naturalistic contexts, respecting the complexity of a learning activity, as it is iterative, involves some sort of design and results in construction of knowledge, ideas or theories on learning. These ideas inform teacher practices directly but should also be seen as guiding the researchers and the teachers in how to develop the design experiment and plan the next step in the iterative cycle. A participatory design approach also ensures a focus on the end-user's needs, motivations, behaviors and goals (Svensson and Ebbesson, 2010; Cooper *et al.*, 2007). In this particular study, the end-users were both the primary teachers and their students in school.

In these workshops, various types of science content (based on the national science curricula) chosen by the teachers were conceptualized and represented through apps running on smartphones and tablet computers to promote students' learning needs (i.e. TPACK). As students (10–12 years old) were the end-users, an important aspect of the D³ process was for teachers, prior to and in between the workshops, to involve their students in the design process. This collaboration was performed through discussions with the students about their needs and skills in relation to the design of the apps. All feedback from students was summarized and presented on the Trello board.

In workshop one

The teachers were introduced to the design process and together with the researchers, analyzed how the use of digital technologies may enhance teaching and learning of science. The teachers were introduced to the TPACK framework, which generated a deep discussion about how technology might or might not influence on students' learning of science as well as a discussion of didactic challenges of teaching specific areas of science. Consequently, this first workshop focused on the problem-orientation process, in which the teacher's own needs and concerns informed the discussions. During this workshop, the relation between TPK and TCK was discussed and as such, the importance of not using digital technologies for their own sake but instead, using it for teaching specific content to a particular group of students.

In workshop two

A modified version of a "future workshop approach" (Ihlström *et al.*, 2005) was used to address identified didactic challenges of teaching and learning science and how meeting these challenges might be supported by appropriate digital functionality (Sjödén, 2015). This approach highlighted potential problem areas with digital technologies in a teaching context and focused on finding ways of addressing these in the forthcoming design process. These problems could be related to both technological knowledge (TK), TPK, TCK and TPACK. The teachers discussed their ideas from different perspectives and shaped them through critical reflection in collaboration with the researchers. First versions of usage scenarios were created that described how students and teachers interacted with the envisioned apps. These scenarios described what the users should do with the digital technology as well as the content and context in which the interaction would take place. The use of scenarios makes ideas easier to communicate between involved stakeholders (Cooper *et al.*, 2007; Svensson and Ebbesson, 2010).

In workshop three

The teachers elaborated on their ideas for apps further by first creating personas, as they continued to develop scenarios. A persona is a user profile, a composite archetypal character derived from user research (Cooper *et al.*, 2007). It is a prototype for a bigger group of users

with similar goals, behaviors and attitudes. Each persona mirrors the real world and enables the designer to focus on a manageable and memorable cast of characters. Personas therefore aid designers to create various designs for different types of people and to design for a specific somebody, rather than a generic everybody. After the creation of different personas, scenarios continued to be developed, reflecting the wants and needs of the personas (so called persona-based scenarios). These scenarios were narrative descriptions of how one or more personas were using the envisioned apps to achieve their specific goals (Cooper *et al.*, 2007). As such, these scenarios were used to discuss functional, non-functional and user requirements of the apps in ways that addressed the different personas (i.e. the students) learning needs. During this workshop the participants framed their discussions of scenarios around the TPACK framework and how to integrate technology, content and pedagogy to develop appropriate, context-specific strategies and representations. One example of a scenario related to the topic of health, sports and human body created during the workshop is presented below:

Who: Robin, 10 years old, does not like sport activities and especially not orienteering. He likes theoretical topics a lot. He also likes technology.

Where: Sports and science day out in the school yard.

What: Robin gets a tablet-PC with the orienteering app and a task to solve the assignments.

When: During sports day.

How: Robin gets a code from the teacher to open the app. There he sees the map of the school yard. He sees a track and where he should walk/run. Each control has a task that is within his area of interest, which makes him feel motivated. When he opens the app, he sees a regular map. In the settings, he chooses a satellite image that he likes better. He likes it because it is real and he recognizes himself. He walks towards the first checkpoint and when he gets there the map flashes and shows that he has arrived. He opens the task, which is symbolized by the control flashing green. A science assignment opens and he thinks it is fun and challenging. Now he can start tracking his own statistics which consists of time, distance, number of found checkpoints (e.g. 3 out of 4). Motivated by the statistics, he starts to run to reach a better time.

When he double checks his answers after he has completed all the checkpoints, he discovers that the answer to question two was not correct. He changes his answer before he sends it to the teacher.

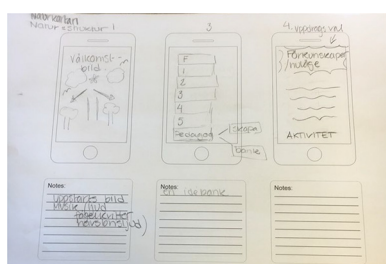


Figure 2. Sketch visualizing one of the ideas from the teachers

In workshop four

The teachers extracted the design requirements from the scenarios. These requirements guided the next phase of the conceptualization and visualization of the apps. This phase consisted of creating mock-ups of the envisioned apps, “quick and dirty” sketches, interactive paper prototypes and other low-fidelity techniques were used. After these visualization activities, the teachers created wireframes detailing the screen design and defining the information hierarchy. Wireframes function as an architectural blueprint for how the user will interact with the digital technology developed and acted as the blueprint for developing interactive high-fidelity prototypes in workshop five. In this particular workshop, we discussed the importance of TK, TCK and TPK for teachers to conceptualize and visualize the content in the apps.

In workshop five

The teachers developed high-fidelity prototypes of the apps. These prototypes contained design templates and user interface components, which were used to rapidly create a graphical user interface based on the wireframes. The high-fidelity prototypes were supposed to represent the final version of the apps to be developed. They also contained hyperlinks between the different screen designs and therefore visualized all the steps in the interaction flow. The prototypes could be exported to existing digital platforms, which enabled ways of demonstrating the prototypes on different smart-phones, tablet computers and personal computers. As such, they constituted the design concepts and specifications that guided the developers who programmed the demonstrators that later on were tested and evaluated by students and teachers. In this last workshop, we had a final discussion about if and then how, the prototype integrated the technology, content and pedagogy to meet the didactical challenges for engaging students in the content.

Design concepts resulting in three different apps

The three groups of teachers (from the different schools) developed three different design concepts that were subsequently developed into three unique mobile apps: MapRun, GeoPass and Explorer:

- (1) MapRun combines orientation to solve different science tasks. The app intends to meet the didactical challenge of engaging students in the learning activities when being on excursions. Often, the students tend to do other things than the task (e.g. climbing trees, chasing each other, etc.) and the teachers have difficulties in making the student to stop and read the information at the different places in the environment. As the students need to be near the orientation control to lock up the task in the app, the MapRun engages the students to visit the different places and further, to engage with the task provided. As such, the app links the orientation activities with global positioning system (GPS) supported features as well as keeping track of the students’ progress orienting and solving different tasks on the course. When students arrive at the different orientation controls on the map, they are given science tasks to be solved either in the physical or virtual space within the app. As the tasks are solved, the student proceeds to the next orientation control. The student and teacher can follow the students’ tracks and progress throughout the whole orientation course. For the teachers, the app supports them in stimulating the students’ engagement in scientific problem solving as well as in experiencing the environment in the near surroundings (both tasks are well grounded in the national primary science curriculum).

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- (2) GeoPass is based on geocaching, i.e. an activity where people hide and seek containers out in the real world with the help of GPS devices marking the spot for the “geocaches.” GeoPass was targeted toward students and in an educational context. The app intends to meet the didactical challenge of triggering students’ curiosity to learn about the nature when being out on field trips. GeoPass is based on the idea of letting students explore local nature as well as historical local places by augmenting the surroundings with the help of digital technology. Furthermore, the app intends to meet the didactical challenge of supporting student’s co-creation of knowledge. GeoPass uses existing facts and content about nature, the environment or historical landmarks that were presented when students went to different physical locations. The app also provided students with a means to add to these facts and the content by updating the database. This was based on the same idea as Wikipedia, to create an interactive encyclopedia for the local region where information and content relating to subjects such as geography, biology and nature could be added. This created an opportunity for students to do their own scientific research with their findings added to the database. The app also created a continuity of information between different classes of students. For example, third graders could do field work and update the database so that second graders could use the app during their field studies.
 - (3) The Explorer app intends to meet the didactical challenge of assigning relevant tasks based on students learning abilities with a flexibility to support the knowledge progression of individual students, as well as for groups of students. Furthermore, the app addresses a didactical challenge concerning supporting students in gathering science facts when out on field studies. The app also addressed a need for documenting students work, as well as teachers need for flexible and dynamic commenting and grading of students’ work. As such, the app addressed a need for providing structure, as well as being a tool to help teachers design tasks based on students’ progression in relation to expected science learning outcomes. The app creates a tool for teachers allocating tasks for students doing field studies in the near environment of the school. The app also acted as a learning platform where the students could document for example the local nature, insects, trees, plants, etc. This was done using the camera in the tablet computer. The students took notes on the tablet as well as wrote their report in the app via the tablet. The teachers could grade and provide feedback on the tasks solved by the students. The app also provided support for different student’s progression and provided a structured way to align learning outcomes with the tasks.

The three digital design concepts and specifications were handed over to the development team responsible for creating the demonstrators. One interaction designer and one programmer were responsible for the development. Two of the involved researchers in the project, as well as all the teachers, were also included in the development process. Nine additional meetings were conducted where the researchers and the teachers were able to provide input, clarification and general feedback to guide the development of the three apps. As such, the development process had an iterative and agile approach to ensure that the apps represented the teachers’ design visions.

About one month of development was allocated to the three demonstrators. This resulted in three fully functional mobile apps that were designed for tablet computers and mobile phones. All the core functionality from the design concepts and specifications were

incorporated and the apps used user and content databases that made them fully implementable in the schools. The apps were deemed as almost ready to be commercially launched. However, they were still called demonstrators, as they were not tested or designed for larger user groups than the involved local schools.

Implementing the apps

The apps were implemented at the teachers' own schools. The three groups of teachers presented the prototypes to their primary students and then used them in their teaching activities during a period of about four weeks. All 14 teachers used the different apps in their teaching, and in total, about 60 students had the opportunity to engage with the apps. As designers of the digital technology, the teachers were experts on why and how the apps could be used and could therefore support the students themselves during the trial period.

After the implementation and field trials, three group interviews were conducted with the teachers. The groups of teachers consisted of three to four participants. A semi-structured interview approach (Patton, 2002) was used based on 12 questions for the teachers (Appendix). The questions for the teachers concerned both their experiences of the design process as well as the use of the apps in their science teaching (i.e. TPACK). Each of the group interviews lasted for about 45 min. All group discussions were recorded and later transcribed.

The data were analyzed through qualitative content analysis, QCA (Schreier, 2013), which is "systematic, flexible and reduces data" (p. 5) and which limits the analysis to "those aspects that are relevant with a view to your research questions" (p. 7). In this part of the analysis, we probed for reflections that captured the technology knowledge dependent components in the TPACK framework. Thus, we searched for illustrative examples where the teachers reflected on aspects related to TK, TPK and TCK as described by Mishra and Koehler (2006, pp. 1027–2028). The identified examples were compared between the two authors and any disagreement were discussed until a consensus was reached. According to Newton and Burgess (2008), the primary forms of validity for knowledge-based research are outcome and process validity. In the analysis, the main action to ensure outcome and process validity was the critical and reflective dialogue between the two researchers when identifying and comparing the different knowledge domains.

In the result section below, key-quotes from the teachers are used to illustrate and highlight how D³ and the apps provided value for teachers and their students in terms of learning opportunities, with a specific focus on how the teachers developed their knowledge, both about designing digital technologies and using these to stimulate students' learning of different science content.

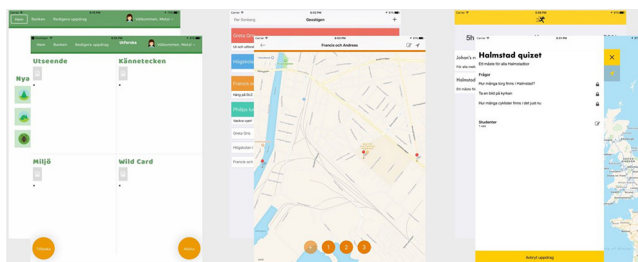


Figure 3.
Screenshots of the
three developed
mobile applications

Results – teachers’ experiences of their knowledge development about designing and using digital technologies

All three groups of teachers gave rich examples of how they developed both their knowledge of using technology (i.e. TK, TPK and TCK) and also the way the D³ process forced them to (re)structure the science content to integrate technology into their teaching. Furthermore, a common problem in science education is that the students do not always find science as engaging and meaningful. Therefore, a challenge in science education is to (un)pack the science content in a way that engages students and promotes their understanding. Within the D³ workshops, the personas and scenarios provided opportunities for the teachers to carefully consider which concepts should be included to promote students’ understanding and how they (through the app) should structure these concepts to better meet students’ learning needs (i.e. TPACK).

In the interviews, all teachers highlighted the collaborative setting, where they worked together with their colleagues and the researchers as fruitful for both their development of pedagogical, content and technological knowledge but also for the integration of this knowledge into their teaching activities (i.e. TPACK). In the quote below, one teacher, Anne, reflects on her experiences:

Anne: It has been valuable to use the personas to reflect on the underlying processes behind the development of an application. How to think about the design, the importance of focusing on the user, i.e. the student and what content you want the student to learn. Everything we want to happen in the application has to be carefully considered in terms of how to make the science content more comprehensible for the learners. Therefore, we must be clear in the way we organize facts and information in the application. As there are many layers and details to be imagined before, we must also be clear in our tasks.

Another aspect that became clear through the teachers’ reflections was how they emphasized that working with colleagues was important for their own professional development. Further, to focus on what matters in a content area and to teach in ways that have a clear purpose and focus is crucial for science understanding. In her reflections, Julia showed how she was supported by colleagues to develop a conceptualization of the subject area, both for herself and for their students. In the quote below, Julia’s experiences indicate how she reflects on the importance of TPK and TCK to represent the content in a way that makes it understandable for students (i.e. TPACK):

Julia: It is fun to create with colleagues and we have learned a lot about how we can use digital tools to help students understand the nature with plants and animals and how things are connected. I have realized the importance of accuracy when using technology to present the content so it becomes understandable. You may need to explain the same concept with multiple images to show an overall perspective.

Another teacher (Sue) also reflected on the need for integrating technology and content and expressed how she had been able to link the science curriculum to convey to students the skills they are currently working on. As she worked with different forms of support structures while designing the app, she became more aware of the importance of organizing the science content and to provide rich explanations to meet students’ difficulties:

Sue: Once we started to design the app using personas and scenarios, we had to reflect on the different science concepts we had developed, both in terms of technology and content. By developing the app, we have been forced to really think through the different support structures to be clear to the students and communicate the facts in an understandable way.

Mary: This is a way to use our profession as teachers and really reflect on how we want an app to look like. Many apps are not created by teachers and they do not really connect to the curricula. We as teachers always try to provide students with the larger pictures of the phenomena, we know what we want students to learn and why. And we also know what the students have experienced before. If we only use an app that we can buy on the market there is not really a holistic perspective of what the students meet but instead some pieces of information here and there.

Further, Anne, noted that designing the app also made her reflect on the importance of not only using digital technology but also using it for a specific science teaching purpose. In the interview, she highlighted how she, together with her colleagues, designed a task in the app about recognizing and describing different trees. The students were going to search facts and write about different trees, take pictures and download them in the app and finally write short stories to every tree. Then, the students went out on an excursion, where they studied the different trees in their real natural contexts. They took new photos and wrote notes on their tablet computer. Then, they returned to the classroom to revise their initial stories and facts about the trees. They also added their self-taken pictures and compared them with the pictures they found on the web. As such, the students were not only engaged in using the app, but also to use the technology with the purpose of developing their investigative skills as well as their science knowledge.

Another teacher (Mary) emphasized how, through doing the personas, she also had to consider the learning needs for different students and as such and reflect on how different students might learn the content in different ways. Therefore, the work of creating the personas also challenges the teachers to (re-)consider students' different ways of understanding a specific content and how this content can be represented through digital technologies (TCK). Knowledge of student' understanding of a particular content and how to plan digital learning activities that meet students' learning needs is a crucial aspect in a teacher's TPACK:

Mary: The process has been very valuable and while thinking through the personas we have been forced to really reflect on how different content can be interpreted and understood by the students through the use of technology.

In the examples above, the teachers' reflections highlight both opportunities and challenges in relation to TPACK with designing and using digital technologies in the way they were provided within the D³ workshops. All three apps were designed to build on students' everyday experiences and as such, contribute to their engagement and motivation to learn about a particular science topic. For example, the MapRun used students' interest in games and sports in the nature to provide opportunities for problem solving and learning of science. The GeoPass was based on geocaching, an activity often performed by the students. In this example, the teachers used the GeoPass to engage students into exploring the nature and learning about plants and trees.

Megan: We saw it as an opportunity for students to actually explore the nature and move out of the classroom. We connected an app where they could find the names of the flowers and in such way, they could find out the correct names for the flower and plants they experienced.

Finally, the Explorer app used the idea of documenting and photographing directly in the same way as snapchat, Facebook or Instagram. Further, the interactive nature of the Explorer, where the teachers could comment directly in the app, provided the teachers with opportunities to recognize student learning difficulties and later explicitly draw on this experience to inform future teaching.

The technology through the apps is emphasized as a means for supporting students' learning of particular content and not as a goal in itself. As such, the teachers' experiences of designing their own digital technology (i.e. constructing the app) makes explicit a foundation of TPACK as they move from TK (knowledge of how to make an app) to TPK (using technology for a pedagogical purpose) to TPACK, where the use of technology is also reflected in relation to students' learning of a particular (science) content.

Discussion – design for learning through digital didactic design

The “digital turn” of the 21st century has seen rapid developments in digital technologies for integration into pedagogical practices. Teachers are encouraged to use technology in the classroom with the premise that technology can help to raise students' motivation, increase interest among students and enhance learning. As [Koehler and Mishra \(2009\)](#) argued, the concept of TPACK:

Allows teachers, researchers and teacher educators to move beyond oversimplified approaches that treat technology as an ‘add-on’ instead to focus again and in a more ecological way, upon the connections among technology, content and pedagogy as they play out in classroom contexts (p. 67).

Good teaching with technology involves a balanced combination of TPACK. In this paper, we have investigated how 14 primary teachers, when taking part in D³ workshops, develop their insights about how digital technologies can be designed and further used in their teaching of science in order to meet students' learning needs (i.e. TPACK). As argued by [Roblyer and Doering \(2010\)](#), TPACK is useful as a way of expressing and thinking of teachers' knowledge and offers a holistic perspective on technology integration into education. The results indicate that the D³ workshops were successful in providing value for teachers to discuss the need for the different technology dependent knowledge domains (TK, TPK and TCK) as well as their integration into TPACK to better promote students' engagement and learning opportunities. This study further indicates that having teachers explicitly articulate their reasoning about designing apps to engage students' learning seems important for exploring the types of knowledge used in these design practices and reflecting on aspects of their teaching with digital technologies likely to influence their TPACK.

[Chittleborough \(2014\)](#) noted that using new technologies in teaching brings with it the risk of using technology only because it entertains. Therefore, teachers need skills to both develop and evaluate the technology for its purpose and have opportunities to practice this in a learning environment. [Voogt and McKenney \(2017\)](#) argued that it is essential to enabling teachers to implement ICT in their teaching, “to select and use hardware and software, identify the affordances (or lack thereof) of specific features and use the tools in pedagogically appropriate and effective ways” (p. 72). This research indicates that the increasing prevalence of ICT offers challenges and opportunities to the teaching and learning of science and to the scientific practice teachers might encounter. It offers solutions by investigating how primary teachers can design their own digital technology to meet students' science learning needs. Although research on the effectiveness of interventions for developing teacher TPACK is limited to date, it might be suggested that helpful starting points could be accessed from the longer-standing body of research on PCK ([Nilsson and Loughran, 2012](#); [Nilsson 2014](#); [Van Driel and Berry, 2012](#)).

Across the field of science education, knowledge about the relation between teachers' use of digital technology and how it might (or might not) promote students'

learning offers access to ideas of how to design and implement teacher professional development programs. This offers enhanced communication opportunities between schools and universities regarding school facilities and expectations of technology to improve teachers' experiences with integrating technology into their learning and teaching. This pragmatic approach to research creates theory and interventions that serve school practice but also produces challenges for design-based researchers. Thus, design experiments have one prospective and one reflective face. First, design studies are implemented with an expected learning process and the means of supporting it. On the other face, design studies are driven by assumptions about the means of supporting a particular form of learning that is to be tested.

Conclusion

In summary, this study presents data from 14 primary teachers participating in D³ workshops. This study can only draw conclusions based on this particular group of teachers and does not provide a basis for generalizing results to a wider population. Furthermore, even if teachers typically don't have the opportunity to develop digital technologies used in their teaching, much can be learned by studying the D³ process. Deep studies of teachers' experiences designing and using digital technologies are important to understand learnings and professional development that leverage educational capacity. Despite few investigated teachers, conclusions and implications can be drawn from D³ as an in-service teaching design to develop teachers' TPACK. These conclusions can be used in wider contexts by teachers and teacher educators when using digital technologies in teaching and learning science.

To conclude, our results suggest that D³ promotes deep learning experiences with a framework that encourages teachers and researchers to study, explore and analyze the applied designs-in-practice, where teachers take part in the design process. As this study indicates, teachers should take an active part in the digital school development and as such, become producer of knowledge and ideas and not only become consumers in the jungle of digital technologies that are implemented on a school level. Therefore, it might well be argued that in science teaching, paying more careful attention to how teachers and researchers work together in collaborative settings, offers one way of better valuing science teachers' professional knowledge of practice. As such, we suggest that digital technologies are not made "for" teachers but instead "by" and "with" teachers.

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Further reading

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Appendix. Interview questions

Questions to teachers

- How did you experience the digital didactical design process?
- What in the workshops did you consider being in particular important for your approach to teach science with digital technologies?
- What in the design process did you experience as challenging? Why?

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- What, during the process did you learn about your own teaching of science with digital technologies?
 - What during the process did you learn about students' experiences of using digital tools (i.e. through students' feedback)?
 - Has the D³ process influenced on your content knowledge? If yes, in what way?
 - How do you experience your role as a teacher in the design process?
 - In what way have you developed your knowledge of teaching and learning with digital tools (i.e. TPACK)?
 - How do you experience that the prototype works in relation to your aim to develop and stimulate students' engagement and learning? Are there other aims with the app?
 - What feedback have you received from your colleagues during the D3 process?
 - Did your app function as you expected?
 - In what way do you want to continue to develop your app?

About the authors

Jesper Lund is Assistant Professor in Informatics at Halmstad University in Sweden. His research interest is primarily focused on user-centered and collaborative digital design and innovation. This includes areas such as user studies, design and evaluation of digital products and services. Most of his studies have been focusing on open and user-centered digital innovation processes within the newspaper and the health technology industries. He is currently engaged in research concerning digital innovation connected to smart cities and communities. His research has been published in a wide array of conferences and journals within the fields of information systems, human-computer interaction and open and user-driven innovation.

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