Developing primary teachers' TPACK through Digital Didactic Design (D^3)

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Introduction

This paper introduces *Digital Didactic Design* (D^3) as a conceptual and practical tool for primary science teachers to develop their professional knowledge, through being co-creators of their own digital tool. Over the past decades, digital technologies have more or less become fully integrated into our daily lives. This is particularly evident in education where access to new information and communication technologies (ICT) has significantly increased. On a national level, the Swedish National Agency for Education raises concerns for how teachers can develop and implement innovative teaching and learning scenarios and activities involving ICT (Skolverket, 2010). In a society where new forms of communication are constantly evolving in relation to new technologies, there is a need to problematize how ICT might (or might not) enhance and support students´ learning. Results from PISA (OECD, 2015) indicate that teachers´ readiness to integrate technology into instruction depends on factors such as whether the technical devices can be accessed in the classroom, whether the school has a digital skills curriculum, and whether teachers in the school have learned how to use these devices to enhance student learning. The results also show no appreciable improvements in student achievement in reading, mathematics or science in the countries that had invested heavily in ICT for education. However, what is also argued is that in order to deliver on the promises technology holds, countries will need a convincing strategy to build teachers' capacity. Technology allows teachers and students to access specialised materials well beyond textbooks, in multiple formats, with little time and space constraints. Perhaps most importantly, technology can support new pedagogies that focus on learners as active participants with tools for inquiry-based pedagogies and collaborative workspace (OECD, 2015). As such, in terms of science education, opportunities arise for ICT use to play a central role in supporting students´ development of scientific knowledge and reasoning. In order to develop resources to be used by teachers in facilitating key aspects of scientific reasoning, both the educational and technological challenges must be met.

Internal and external expectations on teachers´ pedagogical practices put high demands on teachers´ competencies in using technology in their everyday teaching (Livingstone, 2012; Tallvid, 2015). This project builds on the assertion that if teachers take an active part in designing digital tool out of their own teaching and students´ learning needs, they also become more motivated to use and implement digital tool into their teaching practice. We aim to investigate how primary teachers, while participating in a Digital Didactical Design (D^3) program, design applications (apps) to meet students´ science learning needs. In doing so, the project addresses the challenge of developing teachers´ digital competence while also developing new strategies for teaching and learning that utilize the affordances of the technology (Kozma, 2003).

The Swedish National Agency for School (2010) indicates that Swedish schools are world leaders in distributing ICT, but among the worst in using digital technologies in daily teaching practice. Almost 20% of the Swedish teachers view ICT as an intervention that interferes with their teaching, and only one of three teachers agrees with new technological developments and teaching initiatives. Even where technology is available, it is often under-used and hindered by a set of practical constraints and teacher reservations. Teachers have an important role to play in helping students to acquire the necessary skills to become digitally competent in today's society. However, an increasing number of research studies indicates, that despite increased access and improved technical artefacts, few teachers have integrated ICT in the curriculum in a way that leads to significant changes in classroom practice (Livingstone, 2012; Player-Koro, 2012; Tallvid, 2015). Therefore, in-service training that only focuses on "handling the technology" does not support teachers´ use of technology in the classroom.

Mishra and Kohler (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). The teacher needs to understand the relationship between the technical tools (T), pedagogy (P) and content (C) in order to integrate technology into their teaching (Mishra & Koehler, 2006).

This project aims to develop knowledge of how primary teachers, through being part of designing their own digital tool (Digital Didactic Design), develop their TPACK for teaching science to primary students. The D^3 workshops are localized within the Digital Laboratory Centre (DLC) at department of teacher education at Halmstad University. An underlying assumption is that introducing ICT into educational settings impacts not only on which pedagogical approach a teacher can use, but also for how the content is presented to stimulate students´ learning. The TPACK framework stresses the importance of formulating teacher competence as an integration of pedagogical, content and technical knowledge. Used as an analytical tool, the TPACK framework also provides a lens through which to acknowledge and document the areas of overlap between these three domains of knowledge. In our analysis we investigate how these three (pedagogical, content and technological knowledge) are developed and integrated when a group of teachers take part in Digital Didactic Design workshops where they design different digital tool aiming to meet students science learning needs. Our overarching research questions are:

- How do primary teachers develop their TPACK for teaching science while participating in a professional development program based on Digital Didactic Design?

By studying practices where interactive media is developed and designed by the teachers themselves, we acknowledge the potential of technology to significantly enhance teaching and learning. As such the results of the study can contribute to a wider understanding of how the use of ICT in school might promote teachers´ teaching and students´ learning of science.

TPACK as a theoretical framework

Thirty years ago when Shulman (1986, 1987) introduced the term PCK to draw attention to the value of the special amalgam of content knowledge and knowledge of general pedagogy that a teacher needs to be the best possible teacher, issues surrounding technologies were not foregrounded to the extent that they are today. Today, traditional classrooms use a variety of technologies such as Ipads, smartphones, smartboards, apps and 3D-printers and virtual environments. As such, TPACK becomes useful as a way to express and think of specific teachers´ knowledge, which gives a holistic perspective on technology integration into education (Roblyer, & Doering, 2010; Tallvid, 2015).

Professional development to foster TPACK growth among teachers is essential for meeting the needs of future classroom contexts. While PCK integrates domain knowledge and pedagogical knowledge into an understanding of how particular aspects of subject matter can be organised, adapted and represented for instruction, the conception of TPACK adds technological knowledge as a new component that has to blend in with domain and pedagogical knowledge in order to effectively integrate ICT in instructional practices (Vooght & McKenney, 2017). As such, TPACK becomes useful as a way to express and think of specific teachers´ knowledge, which gives a holistic perspective on technology integration into education (Roblyer, & Doering, 2010; Tallvid, 2015).

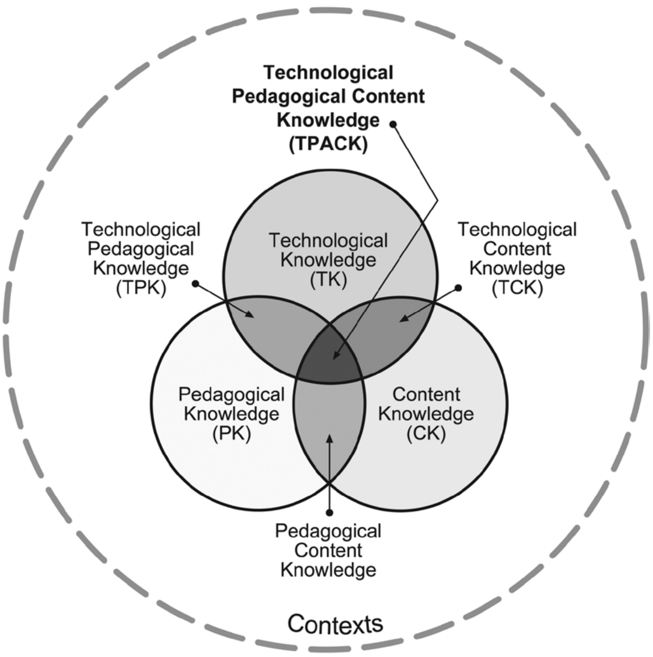

Figure 1 TPACK (Mishra & Koehler, 2006)

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 demands in the choice of teaching approaches that for example acknowledges the learners' different needs. Knowledge of technology refers to the resources, e.g. digital, text, hardware that are available and appropriate to be used for the 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 due to 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 those three domains 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; Pedagogical Content Knowledge (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 Technological Pedagogical Content Knowledge (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. More recent, researchers (e.g. Anderson & Barham, 2013; Koh, Chai & Tay, 2014) have used TPACK as a framework to describe teachers' knowledge for the integration of information and communication technology (ICT) into their teaching. Developing TPACK means, "developing a nuanced understanding of the complex relationships between technology, content, and pedagogy, and using this understanding to develop appropriate, context-specific strategies and representations" (Mishra & Koehler, 2006, p. 1029). As such, TPACK becomes useful as a tool for both developing and capturing teachers´ knowledge and use of digital tools as a way to stimulate students´ learning.

Teachers´ and students´ use of ICT

More than a decade ago, Osborne and Hennessy (2003) stated that along with the changes in views on the nature of science and the role of science education, the increase in the diversity of ICT offers a challenge to science teaching and learning. On the other hand, research indicates (e.g. Skinner & Preece, 2003) that ICT can have benefits as tools for enhancing science teaching and learning in schools. Further, as primary school teachers often lack science content knowledge and confidence in science teaching (e.g. Murphy and Beggs, 2005; Nilsson, 2008), there is a need to organise activities for primary teachers´ professional development to bring about desired changes in their [science] teaching practices.

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 accommodate students with different levels of background knowledge. A focus on scientific literacy indicates a science curriculum that has changed towards matching the new aims of science education where ICT plays an important role. For example, Lundblad and colleagues (2013, 2014) in a design based research project, studied the implementation of augmented reality simulation in physics education. Their research indicated how the use of ICT and digital tool might allow students to observe or interact with simulations, animations or phenomena in novel situations providing opportunities for the development of scientific reasoning skills. While there are changes in the views of the nature of science in primary school, the increasing prevalence of ICT also offers challenge and opportunity to the teaching and learning of science, and to the models of scientific practice teachers and learners might encounter. By investigating how primary teachers design their own digital tool to meet students´ science learning needs, this project considers *both* challenges.

In recent years, some researchers have specifically addressed the role of digital apps as educational tool in different areas of knowledge (e.g. Hirsh-Pasek et. al., 2015; Roblyer, & Doering, 2010; Sjödén, 2015). As a consequence, there is a need for better understanding of teachers´ use of new technologies and what opportunities and challenges in terms of students´ learning of science are provided. To plan learning experiences that challenge students´ learning of science, teachers need to develop better knowledge of science teaching, students' learning, and the curriculum in ways that allow such knowledge to be adequately translated into meaningful practice. In terms of ICT in primary education, Cox and Webb (2004) indicated that there was a strong relationship between the ways in which ICT was used in primary school and students´ attainment outcomes. Digital tool can be used in the classroom to engage students in meaningful interactions, particularly in contexts where students use their imagination, using the technology to promote abstract thought. The teacher's role is important in terms of how students interact with, for example, multimedia simulations of scientific processes using them to stimulate questioning for investigation and requiring them to discuss and reflect on the underlying processes in depth.

The area overview above indicates that previous research in science in primary school as well as previous research on digital tool has tended to direct the focus toward either digital tool with no connection to science, or science without switching to digital tool. Questions that deal with the design and use of digital tool in relation to how the content is understood by the students have not been taken into account to a great extent. With today's increasing digitalization, it is important to identify customer needs and experiences to be able to launch successful ICT innovations targeted towards the user (Rosted, 2005). As such, possibilities to act before and during user involvement activities as well as analysing and evaluating the activities become crucial for a meaningful use of ICT in the school practice.

Research design and collection of data

The research is based on the assertion that teachers, by taking part in the digital didactic design process, are offered new ways of approaching their science teaching and learning practices. The purpose of D^3 is to improve teaching and learning of science by designing and implementing digital tool based on the needs of teachers and students. This includes recommendations on how to choose, combine, implement, and evaluate digital tool for different teaching and learning situations. D^3 facilitates the development of teachers into collaborative designers and evaluators of technology-driven teaching and learning experiences (i.e. learning through reflective making). D^3 also promotes deep learning experiences with a framework that encourages teachers and researchers to study, explore, and analyse the applied designs-in-practice.

The design of the D^3 workshops build on the ideas from a pilot project, funded by Vinnova Makers, that was tried out with a group of teachers during spring 2016. The D^3 workshops are planned to offer opportunities for teachers to interact with researchers in science education and information technology. In this way the workshops are based on ideas of design based research (Cobb et al., 2003) and participatory interaction design (Cooper et al., 2007). Research about user centred design (Norman and Draper, 1986), participatory design (Bødker et al., 1987) and cooperative design (Greenbaum & Kyng, 1991) emerged in the early 80s. One important aspect of participatory design has also been to empower users by involving them in the development processes (Greenbaum & Kyng, 1991). Based on these ideas we will facilitate D^3 workshops enabling teachers, together with their students, to create digital tool supporting teaching and learning of science. The different interactions and communications in the D^3 workshops when the teachers are engaged with designing the digital tool provide means to identify the challenges and possibilities for teachers to integrate pedagogical, content and technical knowledge into TPACK.

Cobb et al. (2003) suggest that design based research is carried out in naturalistic contexts, respecting e.g. the complexity in a learning activity, that it is iterative, involves some sort of design and result in construction of knowledge, ideas, or theories on learning. These ideas are aiming at informing teacher practice directly but should also be seen as guiding the researcher and the teachers in how to develop the design experiment and plan the next step in the iterative cycle. A participatory interaction design approach ensures a focus on the end-users' needs, motivations, behaviours and goals (Cooper et al., 2007; Lund, 2014). In this particular context, the end-users are both students and teachers.

The aim of design based research moves beyond offering explanations of, to designing interventions for. We intend to study how various types of science content (based on the national science curricula) chosen by the teachers are conceptualized and represented with different digital resources in order to promote students´ learning needs. 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. However, during the design study, new and often more specialized assumptions are framed. This creates the iterative approach of design research (Barab & Squire, 2004). The important aspect is that the teachers take part in the design process. As such, the digital service is not made *"to"* teachers but instead *"with"* and *"for"* teachers.

As students (year 4-6) are the end users, an important aspect of the D^3 process is for the teachers to, before and in between the workshops, involve their students in the design process. This was done through discussions with the students, before the workshop, about their needs and skills in relation to the design of the digital prototypes. Between the workshops, the teachers evaluated their ideas together with the students and finally test the prototype:

In workshop one, the teachers were introduced to the design process and, together with the researchers, reason about how the use of digital tool can enhance teaching and learning of science. The teachers discussed their didactic challenges of teaching specific areas of science. In such way, this first workshop focused on the problem-orientation process, in which the teachers own needs and concerns drive the discussions.

In workshop two, a modified version of a future workshop approach (Ihlström et al., 2005) was used to ideate new digital tool addressing identified didactic challenges of teaching and learning science and how meeting these challenges might be supported by appropriate digital functionality (Sjödén, 2014, Sjödén, 2015). The future workshop approach highlights potential problem areas with digital tool in this context and focuses on finding ways of addressing these in the forthcoming design process. The ideas from the future workshop were discussed from different perspectives and the teachers continued to shape their ideas by critically reflect them together with the researchers. First versions of use scenarios were created which described how students and teachers interacted with the digital tool. As such these scenarios described what the users do with the digital tool as well as the context where the interaction takes place. The use of scenarios makes the ideas easier to communicate between involved stakeholders (Cooper et al., 2007; Svensson & Ebbesson, 2010).

In workshop three, the teachers elaborated on their ideas for digital tool further by first creating personas, then continue and develop their use scenarios. A persona is a user profile, a composite archetypal character derived from user research. A persona therefore represents a bigger group of users with similar goals, behaviours and attitudes. Each persona represents a person in the real world and enables the designer to focus on a manageable and memorable cast of characters. Personas therefore aid designers to create different designs for different kinds of people and to design for a specific somebody, rather than a generic everybody. After the creation of different personas, the scenarios should be developed further, now based on the wants and needs of the personas (so called persona-based scenarios). These scenarios are narrative descriptions of how one or more personas are using the envisioned digital tool to achieve their specific goals (Cooper et al., 2007). As such, these scenarios can be used to discuss functional, non-functional, and user requirements of the digital tool to be designed in ways that addresses the different personas needs and goals.

In workshop four, the teachers extracted the design requirements from the scenarios. These would then guide the next phase of the conceptualisation and visualisation of the digital tool. This phase consisted of creating mock-ups of the envisioned digital tool, "quick and dirty" sketches, interactive paper prototypes, and other low-fidelity techniques (Cooper et al., 2007). After these visualization activities, the teachers created wireframes detailing the screen design and defining the information hierarchy. Wireframes functions as an architectural blueprint for how the user will interact with the digital tool developed and act as the blueprint for developing interactive high-fidelity prototypes in workshop five.

In workshop five, the teachers used a digital tool to develop high-fidelity prototypes. These tools contain design templates and user interface components, which can be used to rapidly create a graphical user interface based on the wireframes. The high-fidelity prototypes will look as the final version of the Apps to be developed. They will also contain hyperlinks between the different screen designs and therefore visualize all the steps in the interaction flow. These tools can export the prototypes to existing digital platforms, which enable ways of demonstrating the prototypes on different smart-phones, tablets and computers. As such they constituted the design solutions which will guide a third party developer who creates the demonstrators which will be implemented and tested by students and teachers.

In order to analyse how primary teachers developed their TPACK for teaching science while participating in the Digital Didactic Design workshops, focus group interviews with the teachers were conducted. In the interviews, the teachers were asked to describe their experiences from the workshops. All interviews were transcribed and in order to categorise and describe key aspects in the teachers' reflections, a content analysis was used (Cohen et al., 2007). Content analysis defines a systematic procedure for analysis and examination of the contents of written data. It is a functional method to use with a descriptive research question and several reflections covering the same topic (Cohen et al., 2007; Miles & Huberman, 1994). As described by Schreier (2013) qualitative content analysis, QCA, is ”systematic, flexible and reduces data” (p. 5) and limits the analysis to “those aspects that are relevant with a view to your research questions” (p. 7). As such, qualitative content analysis is a method commonly used when dealing with rich data that requires interpretation.

The transcripts were read carefully and analysed for the purpose of identifying examples of how the teachers´ experienced the professional development program as a way to capture and further develop their TPACK for teaching science.

Findings

All three groups of teachers gave rich examples of how they developed both their knowledge of using technology and also the way the D^3 process forced them to (re) structure the science content in order to integrate technology into their teaching. At the first school, the teachers developed an app to help students to learn about nature, animals and plants. The teachers from the second school designed an app to help students understand about health and the human body. The teachers from the third school designed an app based on geocaching with different scientific problems and tasks. In the interviews, all teachers highlighted the collaborative setting where they worked with both their colleagues and with the researchers as fruitful for both their development of pedagogical, content and technological knowledge, but also for the integration of these knowledge into PCK. In the quote below, Anne reflects on her experiences:

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

Another aspect that became clear through the teachers´ reflections was how they came to see how working in collegial settings was important for their own professional development. In her reflections, Julia notes:

> 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 nature with plants and animals and how things are connected. I have realized the extent of accuracy when presenting the ideas so that it is understandable. You may need to explain the same concept with multiple images to show an overall perspective.

Another teacher 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.

Another teacher, Anne, noted that designing the app also made her reflect on the importance of not only using 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 end the write stores 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 Ipads. Then they returned to the classroom to revise their initial stories and facts about the trees. The 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 technology, but also to use technology with the purpose of developing their investigative skills as well as their science knowledge

Mary emphasized how, through doing the personas, also needs to consider the learning needs for different students and as such, reflect on how different students might learn the content in different ways. As such, the work of creating the personas also challenges the teachers to (re) consider students´ different ways of understanding a specific content. Knowledge of students´ understanding is a crucial aspect in a teacher pedagogical knowledge:

> 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.

In the examples above, the teachers´ reflections highlight both opportunities and challenges with designing and using digital tools in the way they are provided within the D^3 workshops. As become evident in the discussion above is that the technology through the apps is emphasized as a mean for students´ learning of particular content and not as a goal in itself. As such, the teachers´ experiences of designing their own digital tool (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 (as using technology for a pedagogical purpose) to TPACK, where the use of technology is also reflected in relation to students´ learning of a particular content.

Contribution to the teaching and learning of science

The 'digital turn' of the 21st century has seen rapid developments in interactive digital technologies for integration into pedagogical practice. Teachers are encouraged to use technology in the classroom with the premise that technology can help raise 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 technological, pedagogical and content knowledge or TPACK.

Chittleborough (2014) noted that using new technologies in teaching brings with it the risk of mis-using technology or not using technology in a pedagogically effective way—e.g. only using technology 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. Voght and McKinney (2017) argued that TPACK is essential to enabling teachers to implement ICT in their teaching, as it enables teachers 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 project 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. By investigating how primary teachers design their own digital tool to meet students´ science learning needs, this project considers *both* challenges and opportunities.

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 (see e.g. Nilsson & Loughran, 2012; Van Driel & Berry, 2012). Across the field of science education, knowledge about the relation between teachers´ use of digital technology and how it might (or not) promote students´ learning offers access to ideas of how to design and implement teacher professional development programs. Therefore, it might well be suggested that in science teaching, paying more careful attention to the notion of TPACK and how teachers and researchers work together in collaborative settings offers one way of better valuing science teachers´ professional knowledge of practice.

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