Chapter 8
Developing TPACK in Science and Mathematics Teacher Education in Tanzania: A Proof of Concept Study

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The Development of ICT in Education in Tanzania

To ensure the effective training of teachers for integration of technology in their teaching, in 2009 the government of Tanzania introduced the Information and Communication Technology for Teacher Professional Development (ICT-TPD) framework (United Republic of Tanzania [URT], 2009). The ICT-TPD framework is being implemented through the ICT for Science, Mathematics and English (ICT-SME) project and the Bridge IT project, in secondary and primary education respectively. The ICT-SME project was initiated in 2010 and is being implemented under the consultancy of the *Global e-Schools and Communities Initiative* (GESCI). In this project, tutors from selected teacher training colleges are trained to integrate technology in teaching and learning, after which they teach the practicing teachers in selected secondary schools all over the country (Hooker, Mwiyeria, & Verma, 2011). Tutors in the ICT-SME project are provided with laptops and data projectors to facilitate the training of practicing teachers (Hooker et al., 2011). Additionally, the Bridge IT project was initiated in 2011 to introduce ICT into the teaching and learning of science, mathematics and vocational skills in primary education. The Bridge IT project is being implemented in 17 districts in seven regions of Tanzania, where over 150 primary schools are benefiting from it. The project utilizes a large number of ICT tools including radios, videos and TV broadcasts to enhance teaching and learning in the subjects mentioned (URT, 2011).

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A country-wide survey on the status of ICT integration in education showed that in Tanzania ICT use is more prevalent in urban private secondary schools than public schools (Swarts & Wachira, 2010). According to Swarts and Wachira, computer use in schools was limited to teaching of basic ICT skills and no integration into the teaching and learning process was observed. Moreover, a study by Mwalongo (2011) on pre-service and in-service teachers' ICT uses in teaching and learning revealed that the majority of teachers were using computers for preparing notes, teaching and learning resources, preparation of school announcements, reports, letters, students' registration and preparation of examinations. Mwalongo added that almost all surveyed schools had computers and television (TV) sets, and teachers also had mobile phones with cameras, but they did not use the computers and the digital cameras from their mobile phones for academic purposes; in some schools, the available computers were not used at all. According to Swarts and Wachira (2010), some of the factors hindering the use of technology in teaching are: inadequate training and capacity, resulting in underutilization of ICT facilities; a widespread view of ICT as a status symbol rather than a tool; and lack of awareness of the multifaceted range of ICT and how these technologies can be used to address the existing challenges of teaching and learning. Others were lack of common understanding and awareness among stakeholders about the benefits that ICT can bring to education, and lack of skilled manpower to implement technology-enhanced curriculum.[1]

The findings by Hare (2007), Mwalongo (2011), Senzige and Serukesi (2004), Swarts and Wachira (2010), and Vesisenaho (2007) revealed that ICT use in teaching in Tanzania was limited. Across all of these studies, it was acknowledged that technological tools (computers and TVs) were available in almost all secondary schools with electricity connection in urban areas. Although at least two teachers from each school were trained on the use of ICT in teaching, and the ICT tools were somehow available in some schools, the uptake of technology nonetheless remained limited and confined to administrative and personal uses (Swarts & Wachira, 2010). The problems identified by Hare (2007), Mwalongo (2011), and Swarts and Wachira (2010) call for a professional development arrangement to develop teachers' knowledge and skills for integrating technology in teaching,[2] which they currently are lacking. Therefore, a professional development arrangement to develop teachers' technology integration knowledge and skills was designed and implemented for science and mathematics subjects. Science and mathematics subjects have the highest failure rates in schools in Tanzania, and technology is being adopted as an important tool for enhancing teaching and learning in these subjects. The initial stage of the research was a proof of concept study, in which a professional development arrange-

[1] In this chapter, the term "technology-enhanced" is used to describe a lesson or curriculum that is supported by technology; e.g., technology-enhanced science and mathematics lessons.

[2] In this chapter, the term "technology integration" is used to describe the knowledge and skills for using technology in teaching; e.g., technology integration knowledge and skills for science and mathematics teaching.

ment that incorporates 'learning technology by design' was conducted with pre-service teachers. This chapter reports on that study.

Theoretical Underpinnings

In this section, the theoretical underpinnings on which this study was based are presented. First, the potential of technology use for science and mathematics teaching and learning is described, followed by an elaboration of Technological Pedagogical Content Knowledge (TPACK) as a conceptual framework for describing the knowledge teachers need to effectively integrate technology into science and mathematics teaching. After that, the theoretical considerations underpinning collaborative design in teams, the support provided during lesson design in teams and lesson implementation are outlined.

Technology in Science and Mathematics Education

Schools and governments all over the world are introducing technology into education, both as itself a discipline (subject) and as an instructional tool in the other disciplines (Plomp, Anderson, Law, & Quale, 2009). With technology as a discipline, schools and governments have been working towards preparing a generation of people who can use technology such as computers and other sophisticated digital tools in their day-to-day life. As an instructional tool, technology use is being implemented in schools as an important tool for enhancing teaching and learning. According to Webb (2008), the obvious benefit of using technology such as computer simulations in science teaching is to enable the exploration of phenomena that are too difficult or dangerous to investigate experimentally, phenomena that are too small or too large to be seen, and those that happen too fast or too slow for direct observation. Simulations of processes that cannot easily be observed such as meiosis or mitosis in biology permit students to visualise and investigate these phenomena (Webb, 2008). Studies by Keong, Horani, and Daniel (2005) and Niess et al. (2009) reported the value of technology in supporting learner-centered teaching approaches, in which learners use technology to explore and reach an understanding of scientific and mathematical concepts by concentrating on problem-solving processes rather than on calculations related to the problems. Likewise, Özgün-Koca, Meagher, and Edwards (2010) argued that technologies including graphing and some computer-based mathematics learning programs can enhance young students' conceptual and procedural knowledge of mathematics. Keong et al. (2005) reported that the use of technology in teaching science and mathematics improves students' learning by increasing collaboration among students and enhancing the level of communication and sharing of knowledge.

Studies on technology integration in science and mathematics teaching show that teachers' instructional practices are enhanced when they use technology to teach (Jimoyiannis, 2010). According to Özgün-Koca et al. (2010), "as teachers decide whether and how to use technology in their teaching, they need to consider the science or mathematics content that they will teach, the technology that they will use, and the pedagogical methods that they will employ" (p. 11). Teachers also need to reflect on the critical relationships between science or mathematics concepts, the technology they use, and the pedagogy that can support learning. Based on Ozgun-Koca et al. (2010), the question of what teachers need to know and how they should learn it in order to appropriately integrate technology in their science and mathematics teaching is the most important one to address, and it is the primary focus of this chapter.

Niess et al. (2009), citing the National Council of Teachers of Mathematics (2007), asserted that if teachers are to learn how to create a positive environment that promotes collaborative problem-solving, incorporates technology in a meaningful way, invites intellectual exploration, and supports student thinking, they themselves must experience learning in such an environment. Niess and colleagues called for teacher training colleges to train teachers in the same way they would like the graduating teachers to use to teach with technology in schools. There is an overarching conception that teachers' beliefs about how to teach science and mathematics are aligned with how they learned science and mathematics (Niess et al., 2009). Niess and colleagues further argued that teachers who learn to solve science and mathematics problems through the use of graphing calculators, spreadsheets and educational software can better embrace the use of those tools in teaching science and mathematics. Similarly, Richardson (2009) recommended that in order for technology to become a tool for learning mathematics, mathematics teachers must develop an understanding of their subject matter and what it means to teach it using technology. In connection with this, Ferrini-Mundy and Breaux (2008) argued that "in the absence of professional development on instructional technology and curriculum materials that integrates technology use into the lesson content, teachers are not particularly likely to embed technology-based or technology-rich activities into their courses" (p. 437).

Therefore, teachers need to know not only the science and mathematics subjects they teach, but also the manner in which the subject matter can be changed by technology applications (Jimoyiannis, 2010). Teachers need to develop knowledge of various technologies as they are used in teaching and learning settings, and conversely, to know how science and mathematics teaching might change as the result of using particular technologies (Richardson, 2009). According to Niess et al. (2009), the development of such knowledge requires a model that captures the progression of science and mathematics instruction, as teachers integrate technology into their teaching and learning (cf. Jimoyiannis, 2010; Wentworth, Graham, & Tripp, 2008). The need for a model was also addressed by Koehler and Mishra (2009), who argued that at the heart of good teaching there are three components; content, pedagogy and technology, plus the relationships between and among them. This means teachers need to develop not only knowledge of technology, pedagogy and content, but also the knowledge of how these knowledge domains are related. This knowledge requirement for teachers was described by Koehler and Mishra (2005, 2009) in a conceptual framework called Technological Pedagogical Content Knowledge (TPACK). In this study, TPACK is used as a framework for describing the knowledge teachers need to integrate technology in their science and mathematics teaching and as a guide for the design of professional development arrangements to develop technology integration knowledge and skills among pre-service and in-service science and mathematics teachers.

Technological Pedagogical Content Knowledge (TPACK)

TPACK is built on Shulman's (1986) Pedagogical Content Knowledge (PCK), and is intended to capture how teachers' understanding of educational technologies and PCK interact with one another to produce effective teaching with technology. Although Shulman's notion of PCK included the use of technologies in teaching, Mishra and Koehler (2008) argued that because of the immersed role of technology in our society and the rapid changes in technology, there is the need to add technology knowledge (TK) as a third knowledge domain. Technological knowledge is knowledge about the various educational technologies, ranging from low-grade technology such as pencil and paper to digital technology such as the internet, digital video, interactive whiteboard, and so forth (Koehler & Mishra, 2009). While Koehler and Mishra (2009) describe technology as including both analogue and digital technologies, in this study the concept of technological knowledge refers specifically to knowledge of digital technologies. This encompasses, for example, knowing how to operate a computer and knowing how to use a multitude of technological tools (e.g., digital camera, data projectors, etc.) and software tools (PowerPoint, word processors, spreadsheet, e-mail, animations, video, internet, etc.) as well as knowing how to troubleshoot in problematic situations (cf. Voogt, Fisser, Pareja Roblin, Tondeur, & Van Braak, 2013).

Koehler and Mishra (2005) viewed teacher knowledge about technology as important, but not as separated from and unrelated to contexts of teaching; that is, such knowledge is not only about what technology can do, but also, and perhaps more importantly, about what technology can do for them as teachers. They proposed a framework describing teachers' understanding of the complex interplay between technology, content, and pedagogy, or Technological Pedagogical Content Knowledge (TPCK). TPCK occurs as a result of the integration of three components; Technological Knowledge (TK), Pedagogical Knowledge (PK) and Content Knowledge (CK). The interactions between these components lead to the formation of Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and Technological Pedagogical Content Knowledge (TPCK) (Fig. 8.1). Moreover, the circle encompassing all of the components together represents a context. Teachers are supposed to develop the ability to flexibly navigate the spaces defined by the three elements;

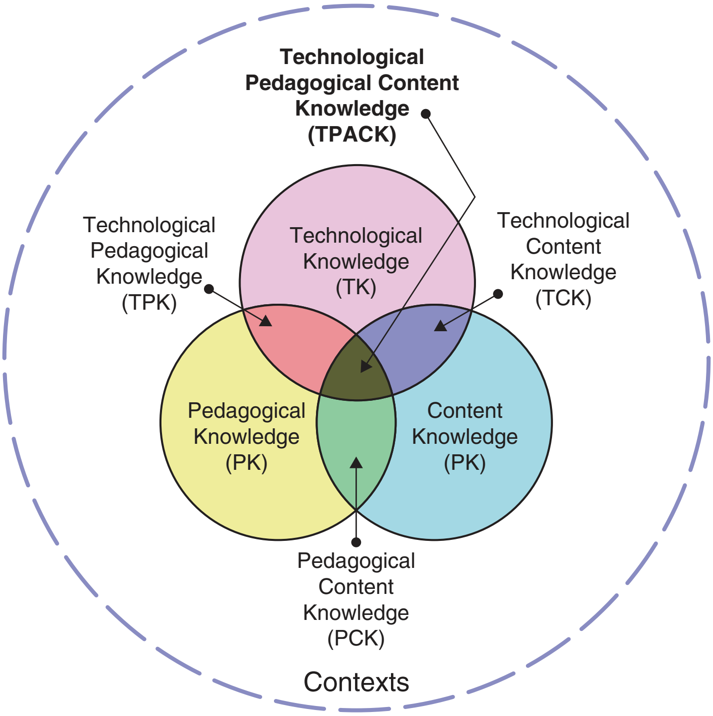

Fig. 8.1 TPACK framework. (Koehler & Mishra, 2009)

content, pedagogy, and technology and the complex interactions among these elements in specific contexts (Koehler & Mishra, 2009). Mishra and Koehler (2006) described TPCK as:

> the basis of good teaching with technology which requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (p. 1029).

TPCK is typically written with an "A" to make it TPACK. According to Thompson and Mishra (2007–2008), the "A" was added to the framework to simplify its pronunciation, as well as to represent the Total PACKage of the components within the framework. Thompson and Mishra (2007–2008) argued that the acronym TPCK is somewhat problematic and difficult to say, and even getting the letters in the correct order is a challenge for most people.

Koehler et al. (2011) argued that most existing technologies are not designed for educational purposes. Making specific technology applications into an instructional tool requires creative input, as well as knowledge and skills from the teacher in order to re-design the technology, the pedagogy and the content. Koehler, Mishra, and Yahya (2007) presented learning technology by design as a promising approach for developing teachers' knowledge and skills for integrating technology into their teaching. According to Koehler et al. (2007), in learning technology by design, teachers work collaboratively in small groups to develop technology-rich solutions to authentic pedagogical problems; in this way, they learn about technology and pedagogy by actually using and designing educational technology to teach specific content. Koehler et al. (2011) described learning technology by design as an effective instructional technique for developing a deeper understanding of the relationships between technology, pedagogy and content. They further argued that design-based learning involves working collaboratively on solving authentic problems rather than learning through lectures and demonstrations. Alayyar, Fisser and Voogt (2011) adopted learning technology by design in a professional development arrangement to develop pre-service teachers' technology integration knowledge and skills in science teaching. In their study, pre-service teachers worked in design teams of three to four to design technology-enhanced science lessons. A study by Agyei and Voogt (2012) similarly used learning technology by design, having pre-service teachers work in groups of two to design technology-enhanced mathematics lessons and subsequently teach those lessons to peers through microteaching. According to Agyei and Voogt (2012) and Alayyar et al. (2011), teachers' collaborative design in teams offers effective learning experiences for developing the knowledge and skills needed to integrate technology in their teaching.

Collaborative Design in Teams

According to Borko, Jacobs, Eiteljorg and Pittman (2008), professional development programs that allow teachers to share, grow professionally and reflect on their practices through inquiry-based interaction can enhance teachers' effectiveness in science teaching. Borko et al. (2008) called for well-designed professional development programs to provide teachers with opportunities to share ideas, opinions, and challenges, to reflect on their technology integration practices and to grow professionally (cf. Guzey & Roehrig, 2009). Teachers' collaboration in teams seems to be an effective professional development technique for providing these conditions (Handelzalts, 2009; Simmie, 2007). Handelzalts (2009) described collaborative design in teams as teacher design teams, and defined these as "a group of at least two teachers from the same or related subjects, working together on a regular basis, with the goal to (re)design and enact (a part of) their common curriculum" (Handelzalts, 2009, p. 7). This study adopted collaborative design in teams as part of a professional development arrangement for developing pre- and in-service teachers' knowledge and skills for integrating technology into their science and mathematics teaching. Teachers' collaborative design in teams has been reported to provide teachers with a creative space to reconsider the teaching of their subjects, the intellectual stimulus of working together and the challenge to move their thinking forward (Simmie, 2007). Thus, it was expected that the development of teachers' technology integration knowledge and skills introduced through collaborative design in teams could have a long-term impact on teachers' use of technology in science and mathematics teaching.

Koehler et al. (2011) claimed that through engaging in pedagogical design with technology around specific content areas, teachers not only gain knowledge of content, pedagogy and technology, but also engage in dialogue and collaboration to develop and scaffold their learning. Through collaborative design in teams, pre-service and in-service teachers can engage in deep conversations about their practices; they are provided with opportunities to experiment and play with ideas, tools and subject matter; and they are offered with contexts to reflect on their learning. Voogt et al. (2011) argued that collaborative design in teams that aims to improve students learning should not only focus on collaborative curriculum (lesson) design, but also on curriculum (lesson) implementation as an integral part of design in teams. In their study, Voogt et al. (2011) found that active involvement in collaborative curriculum (lesson) design helped teachers to change their knowledge, skills and beliefs about good teaching and being a good teacher. In addition, during classroom implementation, teachers were able to show how they changed their classroom practices using the knowledge they had developed during the design activities. According to Riveros, Newton, and Burgess (2012), improvement initiatives for teachers, need to engage the teachers in deeper reflection about the nature of actions and practices in schools, specifically those practices that pertain to professional learning. As part of the collaborative design in teams used in this study, two additional aspects of teachers' learning to integrate technology in science and mathematics teaching were incorporated in the professional development arrangement: support options and the Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002).

The Support

In order to enable teachers to collaborate effectively and learn from their practices, collaborative lesson design, lesson implementation in the classroom and reflection, several support options were provided to teachers in this study. The support options were: collaboration guidelines, an expert, exemplary lessons and online learning materials such as animations, videos and pictures. When working with technology, teachers are subjected to technological and pedagogical challenges related to technology use and integration in the teaching and learning process. In order to address these challenges, scaffolding from a facilitator or an expert is required. As observed in the work by Voogt, Tilya and Van den Akker (2009), modifying traditional teaching techniques to incorporate technology is not easy; it requires teachers to broaden their teaching repertoire. A study by Allan, Erickson, Brookhouse and Johnson (2010) revealed that provision of scaffolded tasks to teachers and the opportunity to collaborate with experts and peers enhances teachers' learning. Moreover, the use of online learning materials such as animations, simulations and videos can save time for teachers in designing technology-enhanced lessons.

Exemplary lessons are another important support for teachers' learning about technology integration in science and mathematics teaching. Exemplary lessons help teachers get a clear picture of the goal of their learning, provide them with the necessary background information and support them while they practice what they have learned in their own classroom (Van den Akker, 1988). According to Voogt (2010), exemplary lessons can offer concrete lessons for use by teachers to provide them with practical experience or can serve as a model for teachers to create their own lesson plans. Above all, working in design teams is always challenging to teachers in terms of arriving at agreement and planning how to spend time (Bakah, 2011). To ensure effective use of time and better design output, teachers require guidelines to provide a sense of direction for their collaboration in design teams. Thus, teachers were provided with the collaboration guidelines to guide them in their discussion and decision-making in the design teams. According to Handelzalts (2009), collaboration guidelines have potential for guiding teachers' interactions in design team meetings.

Research Question

In this study, a professional development arrangement was designed and implemented to develop pre-service and in-service science and mathematics teachers' technology integration knowledge and skills. The study had two important innovations for teachers in Tanzania: collaborative design in teams (offered as a professional development arrangement) for developing technology integration knowledge and skills, and TPACK, which was adopted as a framework for describing the pre-service and in-service teachers' knowledge requirements for integrating technology into their science and mathematics teaching. This chapter provides a general view of the pre-service teachers' perceived and observed knowledge and skills for integrating technology in teaching science and mathematics. It also presents the pre-service teachers' perceptions of the effectiveness of each of the components of the professional development arrangement they attended.

The main research question was: "*What is the impact of pre-service and in-service teachers' participation in the collaborative design of technology-enhanced lessons in order to develop the knowledge and skills for integrating technology into their science and mathematics teaching?*"

Method

This study adopted a design research approach. Plomp (2009) defined design research as:

> the systematic study of designing, developing and evaluating educational interventions (such as programs, teaching-learning strategies and materials, products and systems) as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them. (p. 13).

McKenney and Reeves (2012) characterized design research by its commitment to developing theoretical insights and practical solutions simultaneously, in real-world contexts, and together with stakeholders. They further argued that design research is concerned with the development of usable knowledge, which is constructed during the research and shared with other researchers and practitioners (cf. Wang & Hannafin, 2005). Moreover, design research is iterative and flexible (Reeves, 2006). This was also indicated by Wang and Hannafin (2005), who described design research as a systematic but flexible methodology aimed at improving educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and use of contextually-sensitive design principles and theories.

Reeves (2006) described four important phases in design research: problem analysis, solution development and iterative refinement in evaluation cycles, and reflection on the design principles, which make up the theoretical contribution of the study, and product implementation, or the practical results of the study (cf. McKenney & Reeves, 2012; Plomp, 2009). The results of one phase feed into the next phase. In this study, we based the problem analysis on existing information about the status of technology integration in education in Tanzania (Hare, 2007; Kalinga, 2008; Mwalongo, 2011; Swarts & Wachira, 2010).

The study reported in this chapter was a proof of concept study in which a professional development arrangement that incorporates 'learning technology by design' was conducted with pre-service teachers. Based on studies conducted in similar contexts, one by Agyei (2012) in Ghana and one by Alayyar (2011) in Kuwait, the concept of collaborative design in teams was applied to pre-service teachers training in Tanzania. A context-based professional development arrangement was designed, whereby pre-service teachers participated in a workshop, collaborated in teams to design technology-enhanced science and mathematics lessons, taught the designed lessons to peers through microteaching, and reflected upon the lessons with peers. Unlike professional development arrangements consisting of workshops and/or seminars only, which are commonly implemented in Tanzania (Komba & Nkumbi, 2008), the study reported in this chapter adopted collaborative design in teams (cf. Voogt et al., 2011) as a professional development strategy. Collaborative design in teams is considered to be an effective professional development strategy because it situates teachers' professional development in a meaningful context, allowing teachers to actively engage in the learning process, and providing opportunities for shared ideas through collaboration (Voogt et al., 2011). The professional development arrangement presented in this study adopted the "plan, teach, evaluate, re-plan" approach as proposed by Peker (2009) for pre-service teachers. This approach was implemented by Jimoyiannis (2010) for in-service teachers as "planning, development, evaluation and rethinking". Unlike

Peker (2009) and Jimoyiannis (2010), who began their programs with planning, the professional development arrangement presented in this study began with an introductory workshop to introduce the concept of technology integration in science and mathematics teaching, followed by collaborative design in teams (planning), lesson implementation (teaching), reflection (evaluation) and re-design (re-plan) (Table 8.1).

Thus, this study was conducted to test the effectiveness of this professional development arrangement in the context of the Tanzanian educational system. TPACK was used as a conceptual framework to articulate what was involved in teachers' technology integration knowledge and skills. The study included gathering self-reported and observational data on the pre-service teachers' technology integration knowledge and skills, and their reflection on the intervention activities.

Findings

Findings showed a significant and positive change in Technological Knowledge, Technological Content Knowledge, and Technological Pedagogical Content Knowledge, between pre- and post-intervention, with medium effect sizes. The changes in the remaining TPACK components (Content Knowledge, Pedagogical Knowledge, Pedagogical Content Knowledge, and Technological Pedagogical Knowledge) were insignificant. Peer-rated observation results showed a positive significant change in all technology-related components of TPACK between

Table 8.1 Professional development arrangement

Components	Activities	Duration
Workshop	Introduction of the concept of technology integration in teaching, technological tools that can support learning and the concept of collaborative design in teams	2–4 days with up to 6 hours training per day
	Hands-on activities on how to design technology-enhanced science and mathematics lessons in teams	
Collaborative design in teams	Collaborative design of technology-enhanced science and mathematics lessons	3–4 weeks
	Team meetings were held three times a week for 2–3 hours per day	Three times a week, for 2–3 hours per day
Lesson implementation	Teaching the designed lessons in the classroom	80 min for each team
	One team member taught the lesson while others were moving around the classroom to support the students	
Reflection	Reflection with peers and the expert on the lessons designed	1 day
	Discussion of how to improve the next lesson	
Lesson re-design	Re-design of technology-enhanced lessons to incorporate the ideas discussed during the reflection	3–4 weeks

pre- and post-intervention results. The significant increase in the technology-related components of TPACK confirmed that the professional development arrangement helped teachers to develop their technology integration knowledge and skills. The small increase in Content Knowledge and Pedagogical Content Knowledge could be an indication that the professional development arrangement also helped the teachers to better understand the content they were teaching and the teaching approaches they were applying in teaching this content. An unexpected outcome was that pre-service teachers rated their Pedagogical Knowledge lower at the post-test than at the pre-test. The unexpected small decrease in Pedagogical Knowledge could be an indication that the professional development program made the pre-service teachers aware that their Pedagogical Knowledge was lower than they had initially thought.

The professional development arrangement adopted in this study provided the pre-service teachers with hands-on experience in designing and teaching technology-enhanced lessons. Pre-service teachers were exposed to two important innovations. The first was the opportunity to experience collaborative design and teaching of technology-enhanced lessons in a way that reflected actual classroom teaching. This was important in developing the pre-service teachers' practical experience with the use of technology in designing and teaching science and mathematics subjects. The second was the opportunity to think about technology integration by using TPACK as a conceptual framework. By developing conceptual understanding of TPACK, pre-service teachers were able to integrate technology with science or mathematics and with pedagogy. The opportunity to practice the integration of technology in a way similar to the real classroom, to work in teams and to reflect on their practices is lacking in most teacher training colleges in Tanzania. This study demonstrated the need for authentic learning activities to train pre-service teachers to adequately and effectively integrate technology into their future classrooms.

The findings from this study further confirmed the findings in Ghana and Kuwait (see above) that collaborative design in teams is an effective professional development arrangement for developing technology integration knowledge and skills among pre-service science and mathematics teachers.

Conclusion and Discussion

This study was conducted to investigate the impact of pre-service and in-service teachers' participation in the collaborative design of technology-enhanced lessons as a professional development arrangement for developing knowledge and skills for integrating technology into their science and mathematics teaching. The study emerged from the long-existing problem of low uptake of technology by science and mathematics teachers in Tanzania, and the main research question was answered through a study conducted to test, refine, implement, and evaluate the impact of the professional development arrangement.

Before participation in the professional development arrangement, pre-service and in-service teachers had sufficient Pedagogical Knowledge, Content Knowledge and Pedagogical Content Knowledge, but limited Technological Knowledge, Technological Pedagogical Knowledge, Technological Content Knowledge, and TPACK. Thus, emphasis was required on the technology-related component of TPACK in order to develop teachers' knowledge and skills for integrating technology into their science and mathematics teaching.

The low uptake of technology in schools in Tanzania is a result of teachers' poor conceptual understanding of technology integration in teaching (lack of TPACK), lack of practical experience with technology, and lack of collaboration among teachers. Although teacher training colleges in Tanzania do prepare teachers to use technology in their teaching, a framework describing the knowledge base that teachers need to develop for effective integration of technology into their teaching is missing. Additionally, pre-service teachers have limited opportunities to practice the integration of technology in teaching (cf. Forkosh-Baruch, 2018; Tondeur, Pareja Roblin, van Braak, Fisser, & Voogt, 2013). Moreover, collaboration for learning is lacking in most of the teacher training colleges and schools.

The adoption of collaborative design in teams as a professional development arrangement improved both teachers' self-reported and their observed knowledge related to integrating technology into their science and mathematics teaching. Through collaborative design in teams, teachers reported sharing knowledge, skills, experiences and challenges, and thus, learning from each other. In the teams, teachers also reported reminding each other about the concepts they had learned from the workshop. Findings further showed that collaborative design in teams was effective when teachers were supported through collaboration guidelines, exemplary lessons, online learning materials and an expert with experience in science and education technology.

The long-term impact of the professional development arrangement adopted in this study in the context of the Tanzanian educational system depends on teachers' technology integration knowledge and skills, access to technology, and the ease of use of the available technology. A conceptual model for the continued use of technology in teaching that was developed in this study considers the continued use of technology to be determined by the teachers' professional development, knowledge and skills, access to technology and ease of use of technology. In this model, the professional development, either during the teacher education program (pre-service teachers) or during an in-service arrangement (practicing teachers) is considered to be the initiator of the change in teachers' knowledge and skills for integrating technology into their teaching, which leads to effective use of the available technology in teaching, provided that the available technology is easy to use. Support from the school management is considered to be a catalyst for teachers' use of the technology available at their school for teaching, after participation in the professional development arrangement.

Unlike other design research in which the identification of the problem happens through conducting a feasibility study or situational analysis study (cf. Agyei, 2012; Bakah, 2011; Nihuka, 2011), our research began with a *proof of concept study* in which problem identification was based on previous studies and an in-depth review of literature. According to Plomp (2009), "informed by prior researches and review of relevant literature, researchers in collaboration with practitioners can design and develop workable and effective interventions by carefully studying successive versions (or prototypes) of interventions in their target contexts, …" (p. 13). From the literature it was seen that although technology was available in schools in Tanzania, and teacher training colleges were training teachers to integrate technology into their teaching, technology uptake in schools was low. Thus, a proof of concept study was conducted to find out whether the professional development approach that had been successful in Ghana (Agyei, 2012) and Kuwait (Alayyar, 2011) could also be applied successfully in Tanzania to develop teachers' technology integration knowledge and skills.

Proof of concept studies are common in clinical research and are used synonymously with pilot studies. In clinical research these kinds of studies are used to determine whether a treatment is biologically active or inactive (Thabane et al., 2010). Similarly, in this research, a proof of concept study was conducted to determine whether collaborative design in teams is a feasible and effective approach for developing technology integration knowledge and skills among science and mathematics teachers in Tanzania.

One of the characteristics of design research put forward by McKenney and Reeves (2012) is the complex nature of its interventions, typically consisting of several parts (activities). Little is therefore known about the contribution of each of the activities making up the intervention. In this study, the IMPG model (Clarke & Hollingsworth, 2002) was used to untangle the contribution of each of the components of the intervention to the teachers' development of technology integration knowledge and skills. This helped to explain the importance of each activity that was incorporated in the professional development arrangement presented in this study (i.e., collaborative design in teams, lesson implementation, reflection, and support).

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