Chapter 17

From Needs Analysis to Large-Scale Implementation: Using Collaborative Design to Support ICT Integration

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Introduction

The importance of mathematics in the development of a country should not be underestimated, as it plays a major role in the economy and the social life of its people. Due to its importance, the government of Ghana is committed to ensuring that high quality mathematics education is provided. In spite of government efforts, however, mathematics education has not undergone much change in terms of how it is structured and presented, resulting in consistently low achievement levels among mathematics students in high schools (e.g., see Mullis, Martin, & Foy, 2008; Ottevanger, Van den Akker, & de Feiter, 2007). The method of teaching mathematics is considered one prominent factor among the reasons for this low achievement. Ottevanger et al. (2007) indicated that the most frequently used strategy in mathematics classrooms is the teacher-centred (chalk and talk) approach in which teachers do most of the talking and intellectual work, while students are passive receptacles for the information provided. According to Ottevanger et al. (2007), this type of teaching is heavily dominated by teachers (while students are silent), involves whole class teaching, lots of notes being copied, and hardly any hands-on activities. In most instances, teachers rush to cover all the topics mechanically in order to finish on time for examinations, rather than striving for in-depth student learning (Ottevanger et al., 2007). Such teacher-centred instructional methods have been criticised for failing to prepare students to attain high achievement levels in mathematics (Hartsell, Herron, Fang, & Rathod, 2009). In the recent past, policy makers and mathematics educators have paid increased attention to how to teach mathematics in a way that can be understood and appreciated by students. Numerous researchers have reiterated the potential impact of ICT use on the

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development and expansion of new and existing mathematical concepts and on students' achievement (Beauchamp & Parkinson, 2008; Bottino & Robotti, 2007; So & Kim, 2009). Guerrero (2010) indicated that mathematics is one area that has seen dramatic growth in the influence and applications of ICT on the development of content and the evolution of instruction. Similarly, the Association of Mathematics Teacher Educators (2006) stated that "ICT has become an essential tool for doing mathematics in today's world, and thus ... it is essential for the teaching and learning of mathematics" (p. 1). The government of Ghana shares this view, and considers ICT literacy as an engine for accelerated development, as outlined in the Ghana Information and Communication Technology for Accelerated Development (Ghana ICT4AD Policy, 2003). Ghana introduced ICT into the school curriculum in September, 2007, following the recommendations of the ICT4AD document and the Anamuah-Mensah National Education Review Committee Report (2002). Both documents highlighted the importance of integrating ICT into the curriculum at all levels. Computer literacy has been introduced not only as a new subject in the curriculum, but also as a tool to enhance teaching and learning. The new curriculum in mathematics at the senior high school level encourages teachers to make use of the calculator and the computer for problem solving and investigations of real life situations, in order to help students acquire the habit of analytical thinking and the capacity to apply knowledge in solving practical problems (Ministry of Education (MOE), 2000; Ministry of Education, Science and Sports (MOESS), 2007). As a result, the government and other institutions have invested huge sums of money in procurement of computers and establishment of computer labs in most Senior High Schools (SHS), but it is still unclear whether these computers are being used effectively by teachers in their instruction.

This new orientation to mathematics teaching and learning supported by ICT requires more than recommendations contained in syllabi. Policy makers and training institutions should advocate for radical changes in approaches to teaching. Teachers should adopt new roles and be prepared to be innovative and creative in the integration of ICT in their classroom, thus presenting concepts and theories easily to students and providing them with better education. This chapter presents findings from multiple studies conducted to support teachers in this transition. Specifically, the studies reported here focused on how to enhance professional development arrangements by providing pre-service teachers with opportunities and support to collaboratively design and use ICT-enhanced teaching materials for mathematics instruction.

The Research Context

Teacher Preparation Programmes for Teaching Mathematics in Ghana

The Senior High School (SHS) mathematics curriculum in Ghana focuses on attaining one crucial goal: to enable all Ghanaian young persons to acquire the mathematical skills, insights, attitudes and values that they will need to be successful in their

chosen careers and daily lives (MOESS, 2007). This curriculum is based on the premises that all students can learn mathematics and that all need to learn mathematics. At the SHS level, the student is expected to develop the required mathematical competencies to be able to use his/her knowledge in solving real life problems, and to be well equipped to enter further study and associated vocations in mathematics, science, commerce, industry and a variety of other professions (MOESS, 2007). The rationale of the curriculum has therefore many implications for teaching strategies and the training of mathematics teachers for SHS.

In Ghana, mathematics teacher education for SHS was until recently offered by two main institutions, the University of Cape Coast (UCC) and the University of Education, Winneba (UEW). These two universities are institutions for higher education that have the specific task to train teachers for SHS. The main route in teacher education at both UCC and UEW is the Bachelor of Education qualification programme which is run for a period of 4 years. Three main components are present in the programmes offered by both universities: content courses, education courses and student internship. The content courses are designed to equip students with sufficient content knowledge for their future teaching subjects. The education courses are further sub-divided into general and subject-specific courses. The latter are taught in the subject-specific education departments and denoted as pedagogy courses (for example, the Department Mathematics and ICT Education is responsible for teaching mathematics-related pedagogy courses). The general education courses are taught in other education departments, particularly Educational Foundations and Psychology. Similarly, a separate department referred to as the Teaching Practice Unit is responsible for the administration and organisation of students' placement in schools during their internship.

The studies reported here were conducted within the context of the teacher education programme at UCC.

Mathematics Teacher Preparation Programme and ICT Integration at UCC

UCC is one of the rare sea-front universities in the world. It was established in October, 1962, as a University College, and placed in a special relationship with the University of Ghana, Legon. The University was established based on a dire need for highly qualified and skilled manpower in education to provide leadership and enlightenment. Its original mandate was therefore to train graduate professional teachers for Ghana's second cycle institutions (elsewhere called secondary education) and the Ministry of Education, in order to meet the manpower needs of the country's accelerated education programme at the time. The College of Education Studies (formally known as the Faculty of Education) is one of the largest colleges in terms of student numbers at the University of Cape Coast. It admits close to 40% of the total student population in the regular stream. The College has

four faculties each consisting of a number of departments, centres and/or institutes. Among the departments is the Department of Mathematics and ICT Education which trains mathematics teachers mainly for second cycle institutions in the country.

A review of the courses offered within the 4-year mathematics teacher education programme revealed two issues that were of major importance to this research: the status of ICT integration in teacher preparation and the different teaching methods adopted by instructors in the programme. The only ICT course (computing) offered to the students is during the first semester of the 1st year (taught as a subsidiary and optional subject by the computer science department of the university). In this course, students learn basic computing skills such as familiarity with the operating system, word processing, spreadsheets, and presentation software. Besides the computer literacy course, the mathematics teacher preparation programme also offers a course in Educational Technology, a two-credit hour course in the second semester of year 1. This course is mainly theoretical, merely exposing students to various educational technologies. This means the programme does not give prospective teachers the chance to learn about technology and how to incorporate it into their own teaching. Consequently, pre-service teachers' experience with integrating technology in teaching is limited, making the programme fall short of a practical approach. This leads to the big question as to whether the trained pre-service teachers are sufficiently prepared for new teaching methods that are flexible and involve appropriate use of technology.

Alongside concerns regarding the content of the programme with respect to ICT, instructors at the mathematics teacher preparation programme have limited use, or in most cases, no use of ICT in their teaching practice. Most instructors at this programme use a teacher-centred approach or lecture-based instruction by which the teachers are doing most of the talking and intellectual work, while students are passive receptacles for the information provided. These instructors do not integrate ICT in their instruction due to a lack of technology integration skills (especially for older staff members). At best, some instructors are knowledgeable about ICT applications, but do not have the skills to effectively integrate them in their courses. This is likely to have a ripple effect on the professional practice of these prospective teachers. One possible reason for limited implementation of new technologies by instructors is the dependence on the traditional view of teaching and learning. As Becker (2001) concluded, teachers who believe in a more traditional transmission-oriented approach will find most computer applications incompatible with their instructional goals, and will therefore use a limited range of computer technology in their instruction. Given the observations related to the integration of technology in education and the current emphasis on teacher-centred education at the mathematics teacher preparation programme, it is proper to explore possible ways to incorporate new teaching styles for active learning that use more supportive ICT resources in the mathematics teacher education programme.

Teacher Preparation for ICT Integration

Effective Technology Integration Through Introduction of Technological Pedagogical Content Knowledge (TPACK)

Meaningful use of ICT in education requires teachers to develop the knowledge and skills that enable them to integrate ICT with a suitable pedagogical approach for teaching specific subject matter in a certain context. Keating and Evans (2001) found that pre-service teachers felt comfortable with ICT in their schoolwork and daily practices, but felt unconfident about using ICT in their future classrooms. One possible reason was the comprehensive set of knowledge and skills that these pre-service teachers lacked. Koehler and Mishra (2008) introduced Technological Pedagogical Content Knowledge (TPACK) as a conceptual framework to describe the knowledge base teachers need for effective teaching with ICT. TPACK builds on Shulman's (1986) concept of pedagogical content knowledge, which highlights the importance of the complex interrelationships among teachers' knowledge about content and pedagogy, and the need for teachers to learn about various ways of representing subject matter. Mishra and Koehler outlined the TPACK framework (Koehler & Mishra, 2008; Mishra & Koehler, 2006) in an effort to explain the types of knowledge teachers need in order to integrate ICT into their teaching (see Fig. 17.1).

They argue that effective ICT integration for teaching specific content or subject matter requires understanding of the relationships between three primary forms of knowledge that a teacher needs: Technological Knowledge (TK), Pedagogical Knowledge (PK) and Content Knowledge (CK), as well as the interplay and intersections between them (Pedagogical Content Knowledge, PCK; Technological Content Knowledge, TCK; Technological Pedagogical Knowledge, TPK; and Technological Pedagogical Content Knowledge, TPACK). PCK is knowledge about teaching specific content, as explained by Shulman (1987). TPK is an understanding of how teaching and learning change when a particular ICT application is used. TCK is an understanding of the manner in which ICT and content influence and constrain each other. TPACK is the intersection of all three knowledge areas (TK, CK and PK). Understanding of TPACK is above and beyond the understanding of TK, CK, and PK in isolation. In the current research project, TPACK was used as a conceptual framework to examine the knowledge and skills pre-service math teachers developed about ICT, pedagogy and content. Specifically, the current research project investigated the development of pre-service teachers' TPACK as they used spreadsheets as a tool for enacting a guided activity-based pedagogical approach to

Fig. 17.1 TPACK framework. (Koehler & Mishra, 2008)

teaching mathematics concepts. In the next sections, the theoretical underpinnings of the professional development arrangement are described.

Potential of Spreadsheet for Mathematics Education

Agyei and Voogt (2011a, 2011b) reported that although the government of Ghana has put into place support systems in schools to facilitate access to computers, a lack of ICT infrastructure continues to be an issue in most mathematics classrooms. The study indicated that schools lacked common mathematical software (e.g., Graphic Calculus, Geometer's Sketchpad) typically used in teaching mathematics. Bearing in mind the complexity of the problems most mathematics classrooms in Ghana face in terms of ICT infrastructure and lack of software, spreadsheets were used to enhance a professional development arrangement to develop pre-service technology integration competencies. This is a technology that is readily available in mathematics classrooms and is user-friendly. According to Niess, Sadri, and Lee (2007), teachers who are able to design and enact spreadsheet lessons experience elementary concepts of mathematical modelling, expand their own conceptions of teaching

mathematics with spreadsheets, investigate and expand their knowledge of instructional strategies for integrating spreadsheet learning activities, develop their own knowledge and skills about spreadsheets as tools for exploring and learning mathematics, and explore curricular materials that support learning with and about spreadsheets over an extended period of time. The choice to use spreadsheets in the training programme was appropriate also in the sense that teachers would be able to use existing hardware and software in creative and situation-specific ways to design ICT resources to accomplish their teaching goals in the future.

Activity-Based Learning (ABL) Pedagogical Approach

The idea of ABL is rooted in the common notion that students are active learners rather than passive recipients of information, and that learning, especially meaningful learning, involves activity (Churchill & Wong, 2002). ABL describes a range of pedagogical approaches to teaching mathematics. Its core premises include the requirement that learning should be based on doing hands-on experiments and activities. Churchill (2004) argued that an active interaction with a learning object enables construction of learners' knowledge. Accordingly, he stated that the goal of ABL is for learners to construct mental models that allow for 'higher-order' performance such as applied problem solving and transfer of information and skills. This suggests that in ABL approaches, learners are actively involved, the environment is dynamic, the activities are interactive and student-centred, and much emphasis is placed on collaboration and exchange of ideas. The ABL approach was used in this study to ensure that teaching and learning were based on hands-on activities.

Learning ICT by Collaborative Design and Pre-service Teachers' Design Teams

Research has shown that needs-based collaborative professional development is effective in developing the competencies teachers need to adequately integrate ICT in their classroom practice (Haughey, 2002; MacDonald, 2008). Koehler and Mishra (2005) recommended that developing TPACK should be done through "Learning Technology by Design", an approach in which teachers are involved in collaborative and authentic problem-solving tasks with ICT. Specifically, by actively participating in the design process, teachers build competencies that are sensitive to the subject matter (instead of learning about the ICT in general) and to specific instructional goals (instead of general ones) relevant for addressing the subject matter. The Learning Technology by Design approach adopted in this study seeks to put pre-service teachers in roles as designers of ICT-enhanced environment as they work collaboratively in small groups to develop ICT-based solutions to authentic

pedagogical problems. Angeli and Valanides (2005) argued that such a design-based learning approach contributes to preparing future teachers to be competent to teach with ICT in ways that signify the added value of ICT. Polly, Mims, Shepherd, and Inan (2010) indicated that among other benefits, the flexibility in such collaborations allows pre-service teachers to familiarise themselves with each other and the idea of ICT integration, and contributes to the success of curriculum design teams.

Research Questions

The teacher factor is considered one of the prominent reasons for students' poor achievement in mathematics in Ghana. The instructional approach is mainly teacher-centred, which is characterised by transmittal techniques (chalk and talk, dominated by teacher talk), making students completely dependent on teachers. Recent research findings from mathematics education show that integration of ICT can change the nature of teaching and learning (Agyei & Voogt, 2011a). However, integrating ICT in teaching mathematics is a very complex and difficult task for mathematics teachers in Ghana. They have to learn to use new technologies appropriately and to incorporate ICT in lesson plans and lesson enactment. Professional development is therefore critical towards helping pre-service teachers to develop the proper skill set and required knowledge before such instructional change can occur. The current research focuses on enhancing professional development arrangements in which pre-service teachers collaboratively design and use ICT-supported teaching materials. Based on this purpose, the main research question was formulated as:

How should “collaborative design” in design teams be applied in pre-service teacher education to prepare pre-service mathematics teachers for the integration of ICT in their future lessons?

The research approach applied in this study to seek an answer to the main research question was design-based research. The four main phases of the research were the needs and context analysis, design and implementation, large-scale implementation and a transfer study. The following sub-research questions guided the research phases:

Study 1: Needs and context analysis:

- RQ1: How do prospective and practicing mathematics teachers differ in their attitudes towards ICT integration (will), competencies for ICT integration (skill), access to ICT (tool) and their levels of technology integration?
- RQ2: To what extent do attitudes towards ICT integration (will), competencies for ICT integration (skill) and access to ICT (tool) predict mathematics teachers' technology integration levels?
- RQ3: What are the barriers to ICT use in teaching mathematics in SHS in Ghana?
- RQ4: What are the needs of pre-service and in-service mathematics teachers in teaching mathematics with ICT in SHS in Ghana?

- RQ5: What are the opportunities for ICT use in the teaching of mathematics in SHS in Ghana?

Study 2: Design and implementation:

- RQ6: What are pre-service mathematics teachers' experiences in developing and implementing technology-enhanced lessons through collaborative design teams?
- RQ7: To what extent do pre-service teachers develop knowledge and skill in designing and enacting spreadsheet-supported ABL lessons, and how does this impact secondary school students' learning outcomes?

Study 3: Large-scale implementation

- RQ8: How do the implementation strategies applied in the IT course affect pre-service mathematics teachers' technology competencies (knowledge, skill, and attitudes,)?
- RQ9: What is the impact of the mathematics-specific IT course on pre-service teachers' technology integration competencies (knowledge, skills, and attitudes)?

Study 4: Transfer of learning

- RQ10: What is the potential for implementing instructional technological innovations in teaching senior high school mathematics?

Methodology

Design-Based Research

The main methodology in the studies reported in this chapter was design-based research. Wang and Hannafin (2005) defined design-based research as a systematic but flexible methodology aiming to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings. According to Barab and Squire (2004), design-based research is a series of approaches with the intent of producing artefacts and practices to contribute to a design theory that accounts for and potentially impacts learning and teaching in naturalistic settings. Van den Akker, Gravemeijer, McKenney, and Nieveen (2006) in their extensive work on design-based research have indicated that the compelling argument for initiating design-based research stems from the desire to increase the relevance of research for educational policy and practice, to develop empirically grounded theories through combined study of both the process of learning and the means that support that process, and finally, but not least, to increase the robustness of design practice. There is little debate that, in any domain, the design-based research process tends to be iterative (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). Analysis is

conducted in order to understand how to target a design, and evaluation is both formative (i.e., performed to improve the quality of prototypes) and/or summative (i.e., to determine the impact of the intervention; McKenney, Nieveen, & Van den Akker, 2006).

The studies described in this chapter drew on the multiple theoretical perspectives and research paradigms of design-based research to build understandings of the nature of and conditions for developing pre-service teachers' actual use of ICT resources to improve their mathematics teaching. A context and needs analysis and a literature review were conducted as part of the first stage of the research process. This provided empirically-based awareness about the problem in context, as well as useful information for the formulation of the initial design guidelines that shaped a professional development arrangement. Based on the context and needs analysis, a professional development programme (using collaborative design teams) to engage pre-service teachers in ICT-rich design activities was implemented in three iterations of design, implementation, evaluation and refinement. Data collection during each iteration generated information on how to refine the programme and whether the professional development programme yielded the desired impact, since design-based research integrates the development of solutions to practical problems in learning environments with the identification of reusable design principles (Reeves, 2006). Besides seeking to improve the programme, the evaluation also sought to determine the effectiveness of the technological professional development arrangement for pre-service teachers as far as improving student performance. Furthermore, a final study was conducted to ascertain the potential and conditions for transfer of knowledge and skills in the design and implementation of ICT-enhanced lessons of the pre-service teachers (who were pursuing their careers as mathematics teachers) at various senior high schools. Overall, a design-based research approach proved useful in finding realistic answers to the question posed for the research.

Description of the Studies

The first five research questions were addressed in study 1. *Study 1* investigated the feasibility of teachers' ICT use in mathematics lessons. The first part of Study 1 sought to determine the features of ICT implementation that matched the realities in SHS, and provided useful guidelines for designing a professional development arrangement for teachers' ICT integration. The second part of Study 1 searched for a better understanding of mathematics teachers' attitudes and skills related to ICT integration and their ICT access levels, and the extent to which these parameters influenced mathematics teachers' integration of ICT. A total of 180 educators consisting of 60 in-service mathematics teachers and 120 pre-service mathematics teachers participated in the study. The practicing teachers were selected from 16 SHS ranging across government, mission, private and international schools. Schools were selected because they had a reasonable number of mathematics teachers as well as some kind of ICT infrastructure. The average age of these in-service

teachers was approximately 39 years old, ranging between 25 and 59. There were 52 males and only 8 females. The average teaching experience was approximately 12 years, ranging from as low as 1 year up to 37 years. The pre-service mathematics teachers were from the mathematics teacher education programme at University of Cape Coast (UCC), Ghana. Ninety-five of them were males and 25 were females; they were between 19 and 43 years old, with an average age of nearly 26. Six principals and 14 heads of departments (HoD) in the mathematics section from the 16 SHS were also involved in the study. Further, the study involved the department head of the teacher education programme and an officer from the ICT section of the Ghana Education Service (GES).

Study 2 (research questions 6 and 7), conducted in three iterations, reported results from research that explored Technological Pedagogical Content Knowledge (TPACK) as a framework for developing pre-service teachers' experiences with ICT integration. In particular, the first iteration presented results on teachers' experiences in developing and implementing ICT-enhanced lessons using collaborative design teams as an approach to professional development. Four pre-service mathematics teachers (experimental teachers) and their student peers ($N = 125$) (student-teachers) participated in the study. These experimental teachers had not had any experience with technology-supported lessons, neither as part of their training nor in their pre-university education at the SHS. The student-teachers, who volunteered to be part of the study, were 90 males and 35 females. Just like the experimental teachers, the student teachers had no prior experiences with technology-supported lessons.

The second iteration extended the arrangement of the ICT integration programme to real classroom settings. In this follow-up study, 12 pre-service mathematics teachers participated. The senior high school students ($n = 297$) who participated in the study were from three different high schools. These high school students (from years 1, 2 to 3) were taught lessons by the pre-service teachers. Two hundred twenty-five of them participated in the activity-based lessons supported with spreadsheets, while 72 of them were taught with the traditional approach and served as a control group.

Studies 3 and 4 (research questions 8, 9 and 10) integrated the findings from the previous studies and also identified some inherent conditions and challenges for large-scale implementation of technological innovations in mathematics classrooms. *Study 3* reported on a scale-up study (beyond the group case studies) of the professional development arrangement in a mathematics-specific Instructional Technology (IT) course to foster adoption of the innovation by many pre-service mathematics teachers. More specifically, strategies to develop pre-service teachers' technology integration competencies in the IT course were reported. Pre-service mathematics teachers ($N = 104$; 70 males and 34 females) participated in the study. The pre-service teachers were in their final year of the mathematics teacher education programme. The pre-service teachers had not had any experience with technology-supported lessons, neither as part of their training nor in their pre-university education. Their average age was nearly 25 years old. The participants worked in teams of four; as a result, 26 lessons (by 26 teams) were developed

in the study. A random sample of eight teams was selected, whose the lessons plans and teaching try-outs were presented at the middle and at the end of the course. Another random sample of eight teams presented their end products at the end of the course. All 26 teams were involved in the self-reported survey before and at the end of the course.

In *study 4*, the extent to which beginning teachers were able to transfer knowledge and skills about designing and enacting ICT-enhanced activity-based learning activities to the real classroom situation and inherent challenges identified in this process were examined. One hundred beginning mathematics teachers (66 males, 34 females) were involved in the transfer study. The beginning teachers had participated in a professional development programme during their final year at the teacher education programme at the University of Cape Coast (UCC) to design and enact ICT-enhanced activity-based learning for the first time. These teachers were currently pursuing their careers as mathematics teachers in various senior high schools. All 100 participants responded and completed a questionnaire survey that was administered through email. A random sample of 20 participants was interviewed and 6 of them were voluntarily observed to provide an authentic depiction of the way in which beginning teachers used ICT-ABL in the naturalistic setting of their classroom.

Main Findings

Needs and Context Analysis: Feasibility of ICT Use in Teaching Mathematics

At the initial stage of the research, a context and needs analysis study was conducted to explore the feasibility of ICT use in mathematics teaching in Ghana. The study involved pre-service and in-service mathematics teachers, principals from senior high schools, department heads from the teacher education programme at UCC, and a representative from the curriculum and ICT section of the Ghana Education Service. The purpose of this study was to provide an understanding of the context of mathematics teaching in the Senior High Schools (SHS) and to inform and support the development of ICT integration in the UCC teacher preparation programme. By assessing the perceptions of the various stakeholders regarding the current mathematics curriculum, especially in relation to the use of ICT, challenges and perceived barriers to integrating ICT were reported. Further, ICT training needs of mathematics teachers and existing opportunities to prepare pre-service teachers to effectively design and implement ICT in the teaching of mathematics were also reported.

Findings of the study revealed that mathematics teachers in Ghana do not integrate ICT in their mathematics instruction, and that the most frequently used pedagogical strategy by the teachers was the teacher-centred approach in which teachers

do most of the talking and intellectual work, while students are passive receptacles for the information provided. Among the major perceived barriers that hindered the use of ICT were: lack of knowledge and skills about how to integrate ICT in lessons, and lack of opportunities for both pre- and in-service teachers to learn and practice ICT integration. The results also revealed that there was a major need for the development of teachers' knowledge and skills concerning the integration of ICT in mathematics education. This, however, was not part of the teacher preparatory programme at UCC. The study also revealed that senior high schools lacked common mathematical software (such as Derive, Graphic Calculus, Geometer's Sketchpad, etc.) which can be used for teaching mathematics in the classroom; however, most schools had computer labs.

In spite of the challenges, it was encouraging to find that in-service and pre-service mathematics teachers appeared generally supportive, indicating positive attitudes about using ICT as an instructional tool in their classrooms. An in-depth analysis of pre-service and in-service teachers' will (attitudes), skill (technology competency), and tools (access to technology tools) as essential ingredients for a teacher's integration of ICT into classroom practice was also conducted. The results indicated fairly low ICT competencies, with significant differences existing between pre-service and in-service teachers. The pre-service teachers in this study showed greater anxiety and were less ICT-competent than the in-service teachers. *Computer anxiety* also emerged as the most important dimension of attitudes towards ICT use, while skill was the strongest predictor of classroom integration of ICT for both pre- and in-service teachers. The results of the study suggested that increasing pre- and in-service teachers' ICT skills and decreasing their anxiety should be an integral part of the design of professional development arrangements for pre- and in-service teacher education. Recommendations could be formulated to design professional development opportunities that focus on preparing pre-service teachers to acquire skills regarding how to integrate technology effectively in their instruction, taking the context of the available ICT infrastructure into account.

Design and Implementation (First Iteration): Developing TPACK Through Collaborative Design in a Professional Development Programme

Based on the outcomes of the context and needs analysis study, a professional development programme based on 'learning technology by design' was piloted. TPACK was used as a conceptual framework to examine the knowledge and skills pre-service math teachers developed about ICT, pedagogy and content. The arrangement involved four pre-service teachers who worked collaboratively in design teams (DTs) to design and develop ICT solutions for authentic problems they face in teaching mathematics concepts. The technology learned by the pre-service teachers was spreadsheet applications, because it has the potential to support students'

higher-order thinking in mathematics and is readily available. Pre-service teachers were asked to carefully choose instructional strategies they felt would be useful in supporting their lessons. Exemplary curriculum materials were used to provide pre-service teachers with theoretical and practical insights related to spreadsheet-supported lessons and with hands-on experiences. The DTs developed and modelled their own lessons after receiving the exemplary materials and subsequently taught their peers in an ICT-based environment for the first time.

Pre-service teachers' participation in collaborative design teams increased their knowledge and skills regarding the design and use of ICT-enhanced mathematics lessons. Moreover, pre-service teachers enhanced their knowledge of their subject matter and were able to make intimate connections among their specific content, pedagogy and technology in a collaborative way. Overall, the results of evaluation studies showed that collaborative design was a useful approach for pre-service teachers' development of TPACK. Along with working in DTs, the exemplary materials supported the pre-service teachers by: promoting a better understanding of what integrating technology in lessons is about, promoting pedagogical design capacity, providing concrete, how-to suggestions and facilitating better implementation of the innovation. Although the study showed the potential of TPACK to be a new framework for developing experiences for future teachers, it cannot be said that the professional development programme in the study fully developed the teachers' TPACK. Further opportunities to experience learning about the affordances of technology applications were necessary for teachers to explore additional topics and concepts in their mathematics curricula, and to further develop their TPACK. Lessons from the study supported the contention that TPACK is a useful analytic lens for studying teachers' integration of technology, content, and pedagogical knowledge and skills as they develop over time in "learning technology by design" settings.

Design and Implementation (Second Iteration): Measuring Competencies for Activity-Based Learning with Technology

The second part of the design and implementation study conducted at the same University extended the professional development programme to real classroom settings at various senior high schools. In the arrangement, spreadsheets were presented as a tool for enacting a guided activity-based pedagogical approach to teaching mathematical concepts, referred to as Activity-Based Learning (ABL). Twelve pre-service teachers participated in this second part of the study. The teachers worked in teams of two to develop and model their own spreadsheet-supported lessons for suitable mathematics topics from the SHS curriculum, based on the exemplary materials. Six activity-based mathematics lessons supported with spreadsheets were developed and enacted twice: first by teaching their peer pre-service teachers and later by teaching senior high school students.

The results indicated that the pre-service teachers enacted their lessons using an activity-based instructional approach in which spreadsheets were integrated to help students explore mathematics concepts and perform authentic tasks. In their lesson plans, and during observed instruction, the pre-service teachers demonstrated knowledge and skills by designing and enacting activity-based lessons supported with spreadsheets. This was confirmed by the self-reported development of the knowledge and skills needed to design and enact spreadsheet-supported ABL lessons as indicated by significant gains in all of the TPACK components. To assess the impact of the spreadsheet-supported ABL mathematics lessons on secondary school students' learning outcomes, two pre-service teachers taught their lesson using the spreadsheet-supported ABL pedagogical approach (experimental group) and using a common teacher-centred approach (control group). Significant differences with large effect sizes were found between pre-and post-test mean gains on a performance test in favour of students who experienced the spreadsheet-supported ABL approach compared to the teacher-centred lessons. The findings supported arguments that the spreadsheet-supported ABL approach fosters learner-centred classroom practices, is a useful pedagogical approach, and has potential for improving mathematics teaching, learning and achievement in secondary education. It was concluded that exposing teachers to activity-based learning supported with spreadsheets through collaborative design teams is a good way to help pre-service teachers develop deeper connections between their subject matter, instructional strategy and spreadsheet applications to enhance their TPACK.

Large-Scale Implementation (Third Iteration): Implementing Design Guidelines in a Mathematics-Specific Instructional ICT Course

This study reported on the integration of the professional development programme into a regular mathematics-specific instructional technology course in the mathematics teacher preparation programme of the University of Cape Coast. The design guidelines used and reported in the previous studies were applied to the design of a mathematics-specific course to develop pre-service teachers' spreadsheet integration competencies. In addition to those design guidelines, opportunities for scaffolding authentic ICT experiences were also created for pre-service teachers. The importance of authentic teaching experiences with ICT was demonstrated in teaching try-outs in which pre-service teachers put the lessons they had designed into practice. One hundred and four pre-service mathematics teachers from the teacher preparation programme at UCC enrolled in the course for one semester to develop their ICT integration competencies in teaching mathematics. As was the case in the previous studies, pre-service teachers collaborated in design teams to design spreadsheet-enhanced activity-based lessons for mathematics. Two groups of pre-service teachers were distinguished: those who were involved in trying-out (PT) their

designed lessons by teaching their peers and those who did not have any experience trying-out their lessons by teaching (NPT).

Findings showed that the impact of the Instructional Technology (IT) course on the pre-service teachers' competencies for both PT and NPT was reflected in an increase in their positive attitude towards technology, their self-reported development in TPACK, and their lesson plans and lesson enactment. However, the impact of the IT course differed between pre-service teachers who were involved in the teaching try-out (PT) and those who were not (NPT). Teachers involved in the teaching try-out had less anxiety and more enjoyment, a higher increase in their self-reported TPACK, and lesson plans that better reflected TPACK than pre-service teachers not involved in trying-out their lessons. The pre-service teachers involved in the lesson try-out demonstrated in their lesson plans and lesson enactment their ability to integrate technology in teaching mathematics in a sound way, much more than their peers who did not have the opportunity to teach the lesson to peers and instructors. Thus, although both groups of teachers (PT and NPT) developed and improved their competencies in the IT course, the evidence from the study showed that pre-service teachers involved in the teaching try-out developed their competencies better. One obvious reason for developed and improved competencies, particularly with the PTs, was the authentic technology experiences they acquired during the teaching try-outs. Furthermore, the contribution of feedback from their peers and the researcher during the try-out was an added advantage for improved competencies of PTs.

Transfer of Learning: Examining Factors Affecting Beginning Teachers' Transfer of Learning in Their Professional and Teaching Practice in Ghana

Approximately 6, 18, and 28 months after the third, second and first interventions, respectively, the pre-service mathematics teachers who participated in each study had taken positions in various senior high schools and were pursuing their careers as mathematics teachers. This study employed an embedded mixed-method research design to examine the extent to which 100 of the beginning teachers were able to transfer their knowledge and skills to utilise an ICT-based innovation. The ICT-based innovation consisted of two related components: (1) learning of technology by collaborative design (LTCD) (process) and (2) ICT-enhanced activity-based lessons in mathematics (ICT-ABL) (product). Based on Baldwin and Ford (1988), this study postulated transfer of learning as a function of: (1) characteristics of the ICT-based innovation; (2) beginning teachers' learner characteristics and (3) school environment characteristics. The study sought to arrive at an understanding of how these characteristics influenced transfer of learning in the teachers' professional and teaching practice.

The findings showed that the beginning teachers still hold positive pedagogical views developed during collaborative design in teams in their pre-service teacher

preparation programme, and this seemed to be the most influential factor for teachers' transfer and use of the innovation. The second most influential factor affecting teachers' use of the ICT-based innovation was their learner characteristics. A significant amount of variance attributable to the teachers' learner characteristics explained differences in the level of transfer of the ICT-based innovation. The most critical learner characteristics that were reported were knowledge and skills. It was encouraging to note that most beginning teachers reported having sufficient knowledge and skills, which indicates how well the preparatory programme contributed to teachers' professional learning. School environmental factors were not a significant predictor of transfer of learning, probably because of lack of variability in the school-related factors across the schools. However, interview and observation data indicated that teachers were faced with constraints related to their school environment that contributed to lack of creativity in using certain components of the ICT-based innovation. In particular, lack of access to the ICT infrastructure and an unenthusiastic school culture were mentioned as hindering the use of ICT-ABL.

In conclusion, the study revealed that although a significant amount of variability in the transfer of learning and the utilization of the ICT-based innovation could be attributed to the teacher-related factors, the role of school environment characteristics in influencing transfer of learning in beginning teachers' professional and teaching practice must not be underrated. Further research may be needed to better explore the impact of school environment on transfer.

Discussion

Development of Pre-service Teachers' TPACK

In this research TPACK was used as a conceptual framework for thinking about how to prepare pre-service teachers for ICT integration, because it seemed to be an interesting and useful framework for better understanding what knowledge base teachers need to incorporate ICT in their teaching. TPACK is often assessed on a more generic and abstract level, measuring perceived knowledge that is not configured as specific content knowledge, specific pedagogical knowledge or specific technological knowledge, as was in the case of this research project. The research described focused particularly on the use of spreadsheet applications in enacting a guided activity-based pedagogical approach to develop pre-service teachers' TPACK for teaching mathematics. The research demonstrated that pre-service teachers' TPACK was developed as a result of the intervention. Moreover, the research provided insights about how ABL as a pedagogical approach (representing the "P" in the TPACK model) and spreadsheet applications (representing the "T") need to be designed in close relationship to each other to create a learning environment in which mathematics content could be taught. The focus on the affordance of a specific technology (spreadsheets) and a specific pedagogy (ABL) to foster

higher-order thinking skills in mathematics as a specific operationalisation of TPACK is closer to Shulman's (1986) original conception of Pedagogical Content Knowledge, than the general way TPACK is used in many studies (Voogt, Fisser, Pareja Roblin, Tondeur, & Van Braak, 2012). The results of the studies reported here have shown that this specific focus helped pre-service teachers to develop deep connections between their subject matter, the instructional strategy and the ICT application, fostering their TPACK.

It appears that the explicit focus on ABL use and spreadsheets in particular raises questions as to whether the pre-service teachers will develop their TPACK in similar initiatives using other ICT applications and pedagogical approaches. It is likely that once pre-service teachers understand the context-specific strategies and representations in which new technologies are integrated (cf. Harris, Mishra, & Koehler, 2009; Koehler, Mishra, & Yahya, 2007), they will further develop knowledge and skills related to TPACK in a valid and reliable way. It is also apparent that using multiple data sources is a good way to assess pre-service teachers' TPACK. The research contributed to a better understanding of the nature of pre-service teachers' TPACK development through the multiple types of data collected: while the self-reports assessed what the pre-service teachers thought they knew about teaching spreadsheet-supported ABL lessons (cf. Alayyar, 2011; Kereluik, Casperson, & Akcaoglu, 2010), the assessment of their lesson plans and lesson enactment provided specific information and a concrete representation of what pre-service teachers could actually do with spreadsheets to develop their TPACK (cf. Alayyar, 2011).

Alongside the need to use TPACK as a conceptual framework to guide the development of pre-service teachers' knowledge and skills, it is important that teachers' attitudes towards technology integration be understood in order to appropriately determine the competencies, defined as the integration of knowledge, skills and attitudes, that pre-service mathematics teachers need to integrate technology into their lessons (cf. Farjon, Smits, & Voogt, 2019).

Collaborative Design Teams

Polly et al. (2010) indicated that among other benefits, collaborative design teams allow pre-service teachers to familiarise themselves with each other and the idea of ICT integration, and contribute to the success of curriculum design teams. The reason for adopting collaborative design teams in the current research project was to provide an opportunity for pre-service teachers to design ICT-enhanced curriculum materials to develop their knowledge and skills related to ICT integration. Collaborative design in teams helped pre-service teachers to undertake the kind of pedagogical reasoning that is necessary to effectively integrate technology in their

lessons. In particular, the need to collaborate in lesson design required the pre-service teachers to share knowledge and ideas and to explicitly reason and convince their peers about issues such as why this topic could best be taught with spreadsheets, and why they expect that certain learning activities will contribute to students' learning (Tondeur, Pareja Roblin, van Braak, Voogt, & Prestridge, 2017).

The various studies demonstrated that collaborative design in teams is a viable and effective approach for learning about technology integration. The mathematics teacher education programme at UCC therefore decided to continue with this approach and currently employs collaborative design teams in the preparation of pre-service teachers to integrate technology in education.

Ownership, Transfer and Practicality

The essence of the research project was to foster effective adoption and adaptation of collaborative design in design teams to support the integration of ICT in mathematics education. To realise this, the design-based research project described here aimed to design and implement a professional development arrangement that (1) had concrete artefacts as (one of its) outputs, (2) developed ownership in pre-service teachers regarding the integration of ICT in mathematics teaching, and (3) resulted in transfer of learning to the professional and teaching practice of pre-service teachers. In view of this, the research aimed to prevent failure of implementation of the ICT-based innovation. In this realm, three concepts were considered important:

- *Ownership*, which refers to pre-service mathematics teachers and educators claiming responsibility for actions regarding collaboration in design teams to support ICT integration in teaching mathematics;
- *Transfer of learning*, referring to whether new knowledge, skills and attitudes acquired by pre-service teachers during the pre-service programme were being applied or used in their professional and teaching practice; and
- *Practicality* referring to how feasible the use of collaborative design in design teams can be to support ICT integration by teachers in the classroom situations.

The research demonstrated ownership regarding collaboration in design teams in the sense that the mathematics teacher education programme at UCC has continued with this approach in preparing pre-service teachers to integrate technology in education. Transfer of learning was demonstrated in pre-service teachers' high enthusiasm to apply the new knowledge and skills about collaborative design in design teams to support the integration of ICT in their professional and teaching practice. Findings from the transfer study showed that several months after finishing their teacher education preparatory programme, the pre-service teachers who had just

begun their professional careers still held strong positive pedagogical views about collaboration in design teams to support ICT integration and made attempts to employ aspects of it in their professional and teaching practice. Finally, this research demonstrated that applying collaborative design in design teams to support ICT integration in classroom situations was challenging. Findings showed that these practicality problems resulted from a complex interaction of several variables. However, it appeared that the undermining factor had to do with the passive involvement of various stakeholders, in particular those outside the pre-service teacher preparation programme, such as principals and practicing teachers at the SHS. Although SHS principals and practicing teachers were involved in the first stage of this study, they were minimally involved in the design and implementation of the pre-service professional development programme. This might partly account for the problems pre-service teachers encountered when they, now as beginning teachers, wanted to enact what they had learned in the pre-service programme. In addition to the design of an induction programme for beginning teachers to smooth the transition from teacher preparation to teaching in practice, more attention could have been given in this research to the involvement of SHS personnel during the formative evaluations of the professional development arrangement.

Design Guidelines

One major outcome of applying design-based research in this project has been the construction of a body of design guidelines that could be used to guide future efforts to develop pre-service teachers' experiences with technology integration. Based on this research the following design guidelines have been formulated:

Collaborative Design Teams, in which pre-service teachers work with peers, are an important means to stimulate and support teacher learning. This approach to ICT integration will improve interaction and interdependence among pre-service teachers, making them discover how to share knowledge and ideas as well how to brainstorm about relevant information for their designs.

Exemplary curriculum materials are an important means to use, as they can inspire teachers to learn and provide better understanding of an innovation (cf. Van den Akker, 1988). Exemplary curriculum materials will promote a better understanding of what integrating technology in lessons is about, promote pedagogical design capacity, provide a concrete how-to suggestion and facilitate better implementation of ICT-based innovations.

For more effective collaboration during the use of the exemplary materials and working in design teams, an *orientation programme* is important. Such an orientation programme for pre-service teachers should provide a learning experience where conceptual and theoretical information can be linked to a practical application.

Adoption of technology that is readily available with the potential of supporting students' higher-order thinking in mathematics is key to a successful technology integration intervention. By learning how to use existing hardware and software in creative and situation-specific ways to accomplish their teaching goals, pre-service teachers will be prepared to use ICT in their professional and daily classroom practice.

Scaffolds and authentic technology experiences, such as teaching try-outs with peers, should be an integrated part of a pre-service teacher preparation programme aiming to develop pre-service teachers' technology integration competencies. This allows pre-service teachers to put into practice their designed lesson plans and, through feedback from peers, have access to the necessary scaffolds.

Overall, the research demonstrated that these design guidelines account for developing and improving technology integration competencies, but scaffolding *authentic technology experiences*, including feedback from teaching try-outs, makes the most significant contribution to pre-service teachers' development of technology integration competencies. Authentic teaching experiences with technology makes an important contribution to the reduction of pre-service teachers' anxieties, thereby increasing their enthusiasm to use technology in their instruction.

Conclusion

Based on the responses and experiences of the pre-service teachers, the research demonstrated that pre-service teachers developed TPACK and that they felt prepared to use ICT effectively in their classrooms. The outcomes of the research showed that collaborative design in design teams in pre-service teacher education is a viable and effective approach to prepare pre-service mathematics teachers for the integration of technology and activity-based learning in mathematics lessons. Thus, in order to *design* and *enact* ICT-enhanced mathematics lessons, opportunities were provided to develop the pre-service teachers' knowledge and skills in making intimate connections between technology (spreadsheets), content (mathematics) and pedagogy (activity-based learning). While pre-service teachers *collaborated* during design and enactment, knowledge and attitudes about ICT and activity-based learning became explicit, which helped them to reflect on their experiences, and hence fostered learning.

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