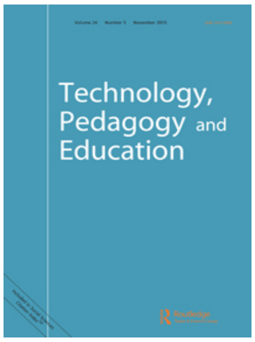

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Pre-service teachers' TPACK competencies for spreadsheet integration: insights from a mathematics-specific instructional technology course

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This article explored the impact of strategies applied in a mathematics instructional technology course for developing technology integration competencies, in particular in the use of spreadsheets, in pre-service teachers. In this respect, 104 pre-service mathematics teachers from a teacher training programme in Ghana enrolled in the mathematics instructional technology course for one semester. Strategies applied in designing the course were: aligning theory and practice, collaborative design, learning technology by design, modelling how to use technology and scaffolding authentic technology experiences. The pre-service teachers' technology integration competencies were assessed through analysis of lesson plans and lesson observations, their self-reported technological pedagogical content knowledge and attitudes towards technology. Findings show that pre-service teachers' technology integration competencies improved after participation in the course. All strategies were considered important, but in particular, scaffolding authentic technology experiences including feedback from teaching try-outs made significant contributions to the pre-service teachers' developed technology integration competencies. The study provides guidelines that can serve as a benchmark for implementing strategies in the design of a subject-specific teacher education programme in preparing pre-service teachers to integrate technology in teaching.

Keywords: technology integration; pre-service teachers; integration competencies; teacher education; mathematics education

Introduction

In spite of the positive impact of the use of technology on students' mathematics achievement (Beauchamp & Parkinson, 2008; Bottino & Robotti, 2007), evidence suggests that pre-service teachers do not feel prepared to effectively use technology in their classrooms (e.g. Kay, 2006). This situation does not appear different from the mathematics teachers' preparation programmes in Ghana. In Ghana mathematics teacher education is provided by two main institutions. These two universities are institutes for higher education that have the specific task to prepare teachers for senior high schools. In his review of the courses offered within the four-year mathematics teacher education programme in one of the institutions, Agyei (2012)

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unfolded two issues which were of major importance: the status of the integration of information and communications technology (ICT) integration in teacher preparation and the different teaching methods adopted by instructors in the programme. Alongside concerns regarding the content of the programme with respect to ICT, instructors at the mathematics teachers' preparation programme have limited use or often no use of ICT in their teaching process. Most instructors at this programme use lecture-based instruction in which teachers do most of the talking and intellectual work, while students are passive receptacles of the information provided. This is likely to have a ripple effect on the professional practice of these prospective teachers and leads to the question of whether pre-service teachers are sufficiently prepared for new teaching methods including appropriate use of ICT. With this lack of attention on the integration of ICT in mathematics education and the current emphasis on a teacher-centred approach in mathematics teacher preparation programmes in the context under consideration, this article explores the impact of different strategies applied in designing a mathematics-specific instructional technology course on pre-service teachers' competencies to integrate technology in their lessons.

Recent calls have indicated that to prepare pre-service teachers for effective technology integration, teacher education programmes need to help pre-service teachers to build knowledge of sound pedagogical practices, technology skills and content knowledge, as well as how these knowledge domains relate to one another (Koehler & Mishra, 2008; Mishra & Koehler, 2006). Kay (2006) also indicated that there is no consolidated picture on how to effectively introduce technology to pre-service teachers. Studies reported different strategies to prepare pre-service teachers to integrate technology into their lessons. A comprehensive description and evaluation of strategies is therefore a necessary step to guide researchers and educators to implement effective and meaningful use of technology in teacher education programmes.

Strategies for technology integration in pre-service teacher education

Teacher education programmes struggle with selecting and implementing the most effective strategies on how to prepare pre-service teachers to integrate technology in their future lessons (Goktas, Yıldırım, & Yıldırım, 2008). Numerous teacher education programmes have made extensive efforts to implement effective and meaningful use of technology, however the strategies used to attain these goals are complex, diverse, often conflicting and rarely well evaluated (Kay, 2006). Teacher education programmes have involved a wide range of approaches throughout the curriculum (based on Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010; Polly, Mims, Shepherd, & Inan, 2010): information delivery of technology integration content (e.g. lectures, podcasts), hands-on technology skill-building activities (e.g. workshops), practice with technology integration in the field (e.g. field experiences) and technology integration reflections (e.g. electronic portfolios). Tondeur et al. (2012) reviewed qualitative studies that focused on strategies to prepare pre-service teachers to integrate technology into their lessons. They identified 12 key themes that need to be in place in the teachers' education programme in preparing pre-service teachers in technology integration. The key themes are either related to the preparation of pre-service teachers (e.g. using teacher educators as role models, learning technology by design, scaffolding authentic technology experiences) or to conditions necessary at the institutional level (e.g. technology planning and leadership, cooperation within and between institutions, training staff). This study has applied the first set of key themes as strategies in the design of the mathematics instructional technology course.

Strategy 1: aligning theory and practice

Studies (e.g. Brush et al., 2003; Jang, 2008) have shown that in preparing teachers to use technology (e.g. how to use specific software), it seems better to link conceptual or theoretical information to practice so that pre-service teachers can understand the reasons behind using ICT rather than presenting the content in isolation. In this study, the mathematics instructional course makes use of a combination of theory during lectures and practice during lab sessions to provide learning experiences in which knowledge/skill gained can be applied.

Strategy 2: collaborating with peers

According to Angeli and Valanides (2009), collaboration with peers appears to provide a time-efficient, high-challenge, low-threat learning environment for pre-service teachers. It also makes pre-service teachers aware of the fact that in order to evaluate others, they first had to reflect on their own performance and evaluate themselves (Tearle & Golder, 2008). In this study, collaborative design teams are used to stimulate teacher learning.

Strategy 3: learning technology by design

Research suggests that the opportunity to (re-)design technology-enhanced curriculum materials is a promising strategy for pre-service teachers' technology integration (e.g. Polly et al., 2010), which is the reason to have collaborative design teams in the mathematics instructional technology course in this study.

Strategy 4: modelling how to use technology

According to Voogt (2010), exemplary materials can provide pre-service teachers with theoretical and practical insights into technology-supported learner-centred lessons and hands-on experience. Similarly, Brush et al. (2003) and Haydn and Barton (2007) described how pre-service teachers adopted the strategies modelled to them during their pre-service education. In the study, the mathematics instructional technology course makes use of exemplary curriculum materials and demonstration lessons to model appropriate technology use.

Strategy 5: scaffolding authentic technology experiences

Tondeur et al. (2012) highlighted the importance of applying knowledge about educational technology in authentic technology experiences. Tearle and Golder (2008) stressed that 'watching' technology being used could not substitute for 'doing'. In this respect, teaching try-out by pre-service teachers was an important component of the instructional technology course to provide them with hands-on technology experiences.

Technology integration in mathematics: pre-service teachers' competencies

With the potential of technology, there is a need for (pre-service) mathematics teachers to redefine classroom environments to create learning experiences that engage the power of technology to involve students in learning mathematics. (Pre-service) mathematics teachers find themselves confronted with challenges and questions of how to develop their knowledge and skills for teaching and learning mathematics topics with technology (Niess, 2011). Alongside the need to develop their knowledge and skills, teachers' attitudes towards technology integration also need to be understood to appropriately determine competencies which (pre-service) mathematics teachers need to integrate technology into their lessons. A body of literature on teachers' use of computers in instruction shows that attitude plays a key role in determining computer use as a learning tool and determining the likelihood that teachers will use technology for teaching and learning (Agyei & Voogt, 2011; Christensen & Knezek, 2008). To determine the type of knowledge and skills which teachers need to integrate technology into their instructional practice, Mishra and Koehler introduced the technological pedagogical content knowledge (TPACK) framework (Koehler & Mishra, 2008; Mishra & Koehler, 2006). Koehler and Mishra (2008) argued that effective ICT integration for teaching specific content or subject matter requires understanding 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: pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK) and technological pedagogical content knowledge between them. The framework explicitly acknowledges that effective pedagogical use of technology is deeply influenced by the content domain in which the knowledge types are situated. Cox and Graham (2009) referred to TPACK as teachers' knowledge of how to coordinate the use of subject-specific activities or topic-specific activities with topic-specific representations using emerging technologies to facilitate student learning. This suggests that the measurement of TPACK should be tailored towards specific content knowledge, specific pedagogical knowledge and specific technological knowledge; however, in most studies, TPACK has often been assessed on a more generic and abstract level. This study particularly focused on specific spreadsheet applications in enacting a guided activity-based pedagogical approach to develop pre-service teachers' TPACK in teaching mathematics. In the study TPACK has been used as a conceptual framework to examine the knowledge and skills pre-service mathematics teachers develop as they design and enact activity-based lessons supported with technology as part of an instructional technology course. TPACK seemed to be a useful framework for preparing these novice pre-service teachers to teach with technology for the following reasons: TPACK may help them to better understand the potential contributions of the emerging technologies. Secondly, the added value of TPACK is the tendency to support students in learning conceptual and procedural knowledge of a particular subject (cf. Cox & Graham, 2009; Niess, 2011) and impact on the curriculum.

As shown in Figure 1, the technology (TK_{ss}) learned by the pre-service teachers were spreadsheet applications for mathematics. Spreadsheet software is readily available in Ghana's senior high schools. Niess, van Zee, and Gillow-Wilese (2010–11) indicated that spreadsheets contain features for modelling and analysing change, providing pre-service teachers with tools that support mathematics concepts and

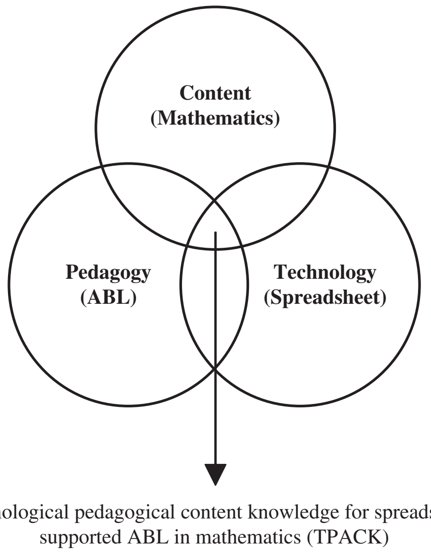

Figure 1. Framework of TPACK used in this study.

processes for accurate analysis. The pedagogical knowledge (PK_{ABL}) examined in this study was activity-based learning (ABL). The idea of ABL is rooted in the common notion that students are active learners rather than passive recipients of information (Churchill & Wong, 2002). ABL has been used to ensure that teaching and learning was based on hands-on activities. Content knowledge (CK_{maths}) was mathematics which is the pre-service teachers' teaching subject area.

In this study, the TPACK components are defined as follows:

- Content knowledge (CK_{maths}): knowledge about mathematical concepts.
- Pedagogical knowledge (PK_{ABL}): knowledge and skills about applying ABL teaching strategies.
- Technological knowledge (TK_{ss}): knowledge and skills about use of spreadsheets, their affordances and constraints.
- Pedagogical content knowledge (PCK_{ABL}): knowledge and skills about how to apply ABL to teach particular mathematics content.
- Technological content knowledge (TCK_{ss}): knowledge and skills about representing mathematical concepts in a spreadsheet.
- Technological pedagogical knowledge (TPK_{ABL}): knowledge and skills about how to use spreadsheets in ABL.
- Technological pedagogical content knowledge ($TPCK_{maths}$): knowledge and skills about representing mathematical concepts with spreadsheets using ABL.

Research question

The main research question of the study is: How do the strategies applied in the mathematics instructional technology course have an impact on pre-service mathematics teachers' technology competencies (attitudes, knowledge and skills)?

In the study, technology integration competencies will be assessed by analysing pre-service teachers' TPACK evidence in their lesson plans and observed lessons as well as their self-reports.

The mathematics-specific instructional technology course programme

This research has been conducted in the context of the Department of Science and Mathematics Education in one of the two major teacher preparation programmes in Ghana. Based on the design principles described above and experiences with the approach in two small pilot studies (Agyei, 2012) in the same context, the instructional technology course has been redesigned and applied for the first time during the spring semester for final-year pre-service mathematics teachers. The 14-week course required pre-service teachers to attend one two-hour lecture and one two-hour laboratory session per week. Table 1 presents an overview of the activities in the course in relation to strategies for developing TPACK.

The lectures were meant to update the students on theoretical foundation/concepts (e.g. TPACK framework, collaborative teacher design, ABL and the pedagogical task). Two technology-based lesson models (designed by the researcher) were taught by the researcher as demonstration lessons and discussed in class during two lecture periods. Other lecture periods included interactive discussions on readings, class assignments and projects. A typical lab session included small group components in which design teams worked on their assignments and project. Implementation of lessons in which teams taught their peers during teaching try-outs was a necessary

Table 1. Outline of the instructional technology course and strategies for technology integration.

DT activities	Activity	Strategy	Integration competencies	Time frame
Introduction to technology-based possibilities of teaching mathematics	l/ls	1	$TPCK_{maths}$	4 weeks
Introduction to learning by design (collaboration)	l	1	–	
Introduction to computer skills (and spreadsheets in particular)	l/ls	1,2	TK_{ss}	
Introduction to TPACK concept	l	1	$TPCK_{maths}$	
Introduction to learner-centred approaches (and ABL of teaching maths)	l	1	PK_{ABL} /PCK_{ABL}	
Introduction/demonstration of activity-based lessons supported by spreadsheet (exemplary material) and discussion	l/ls	1,4	$TPCK_{maths}$	
Scouting spreadsheet techniques that support mathematics teaching	ls	1,2,3,4	TPK_{ABL}	5 weeks
Development of mathematics activities supported by spreadsheets and lesson development	ls	1,2,3,4	TCK_{ss}	
Teaching of activity-based lessons supported by spreadsheets to peers/researcher	ci	1,5	$TPCK_{maths}$	5 weeks
Revision of the developed lesson materials based on feedback	ci/ls	1,3	$TPCK_{maths}$	

l = lecture; ls = laboratory session; ci = classroom implementation component. To complete their semester's long project, the pre-service mathematics teachers worked in teams of four to identify mathematics topics (concepts) from the senior high school curriculum to be taught with technology; identified appropriate spreadsheet applications for the topic; designed and developed appropriate learning activities based on ABL; incorporated activities in lesson plans and taught (in teaching try-outs) their lessons accordingly. Each lesson document comprised a teacher guide to help set up the environment, a plan for lesson implementation and a student worksheet which promoted hands-on activities during lesson implementation. Eight teams presented their lessons in the middle of the course (6th–7th week) and at the end to their peers and instructors. The lessons were taught in a classroom with a computer and an LCD projector. The same teams and eight others presented their lessons at the end (12th–14th week) of the course. Two instructors, the researcher and the original course instructor, were involved. The researcher's role was demonstrative during the lecture sessions and consultative during the lab sessions. The other instructor helped the researcher and supported students during lab sessions.

Method

Participants

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 in technology-supported lessons, neither as part of their training nor in their pre-university education. The average age was nearly 25 years. 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 of which 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.

Instruments

Table 2 gives a general overview of the different instruments used, the purpose, the number of participants that responded to the instrument and their stage of administration during the instructional technology course.

TPACK Lesson Plan Rubric

A TPACK Lesson Plan Rubric was adapted from the Technology Integration Assessment Rubric (TIAR), which Harris, Grandgenett, and Hofer (2010) created and tested and found to be a valid and reliable instrument to assess TPACK evident in teachers' written lesson plans. While TIAR is a general rubric to determine TPACK in lesson plans, adaptations were made to fit TPACK for spreadsheet-supported ABL in mathematics. The rubric consisted of seven different criteria (see Table 3); each criterion was scored as: *not at all* (1), *minimal* (2) and *strong* (3) with a minimum score of 7 and a maximum of 21. In analysing the documents, coding based on categories of TPACK was done for each lesson. Each code was then assessed based on criteria of

Table 2. Overview of instruments and their stages of administration.

Instrument	Teams (N)	Construct	Measurement type	TPACK data		Stage of adminis-tration		
				Source	Type	B	M	E
TPACK Lesson Plan Rubric	8	Spreadsheet integration competence	Performance assessment	Team	Artefact		✓	✓
TPACK Observation Rubric	8	Spreadsheet integration competence	Performance assessment	Team	Observable		✓	✓
Design team reports	26	Developing spreadsheet integration competence	Reports	Team	Artefact			✓
TPACK Survey	26	Self-confidence of spreadsheet integration competence	Survey	Individual	Self-report	✓		✓
TAC questionnaire	26	Self-belief of spreadsheet integration competence	Survey	Individual	Self-report	✓		✓

*B = Before, M = Mid, E = End of instructional technology course.

Table 3. Criteria for analysing spreadsheet-supported ABL lesson plans.

Appropriately spelt-out subject matter of mathematics lesson (CK_{maths})
ABL strategies support to mathematics learning (PK_{ABL})
Clearly designed spreadsheet techniques that can support transfer of knowledge (TK_{ss})
Support of ABL strategies to mathematics lesson goals (PCK_{ABL})
Alignment of spreadsheet techniques to mathematics lesson goals (TCK_{ss})
Support of spreadsheet to ABL strategies (TPK_{ABL})
Fit of mathematics content, ABL strategies and spreadsheet techniques together within the instructional plan ($TPCK_{maths}$)

the rubric, after which the average score for each category was determined. To find TPACK evidence in the document, the sum of all the categories of TPACK was determined. Eight lesson documents were analysed twice: at the middle and the end of the programme; and another eight at the end of the course. Interrater reliability (Cohen's $\kappa = 0.86$) was calculated using a sample of three lesson plans.

TPACK Observation Rubric

The Observation Rubric was adapted from the valid and reliable TPACK-based Technology Integration Observation Instrument (Hofer, Grandgenett, Harris, & Swan, 2011), which was developed and used to assess TPACK evidence in observed instruction. Adaptations were made to be able to observe TPACK for spreadsheet-supported ABL in mathematics. The observation instrument consisted of 20 items, which could be scored as *not at all* = 1, *partly observed* = 2 and *observed* = 3 with a minimum score of 20 and maximum 60. To analyse a lesson, the total score (TPACK score) was obtained for all the 20 items. Eight lessons were observed at the middle and end of the programme respectively; and another eight at the end of the course. Cohen's κ for two independent raters was 0.84. Table 4 gives an overview of sample questions for each TPACK knowledge type construct that was assessed in the lesson: enlargement with scale factor *k*.

TPACK Survey

The TPACK Survey measured teachers' self-report development in their TPACK. The questionnaire was adapted from Schmidt et al. (2009) and had a 5-point Likert scale format (from 1 = *strongly agree* to 5 = *strongly disagree*). The instrument was administered twice: before and after the instructional technology course for all the 104 (all 26 teams) participants. Table 5 provides an overview of sample questions for each TPACK knowledge type used to assess the pre-service teachers' development in TPACK.

Teachers' Attitudes towards Computers (TAC) questionnaire

The TAC (Christensen & Knezek, 2000) measures pre-service teachers' attitudes towards technology. Six sub-scales of the TAC questionnaire instrument were used: Enjoyment (Cronbach's $\alpha = 0.73$), the pleasure someone experiences when using and talking about computers; Anxiety (Cronbach's $\alpha = 72$), fear of using and talking about computers; Benefit (Cronbach's $\alpha = 0.88$), perceived advantages of using computers in the class; Interaction (Cronbach's $\alpha = 0.83$), willingness to use possible applications of computers for information dissemination; Instructional Productivity

Table 4. Sample items for each TPACK knowledge type construct.

Sample items	Example of observed or partly observed practice	3	2	1
Subject matter (CK_{maths})				
Clearly introducing mathematics concept and learning goals of lesson	The scale factor k is the ratio of the image to the object: $(k = \frac{image\ size}{object\ size})$	✓		
Pedagogical knowledge (PK_{ABL})				
Engaging students in solving authentic problems using teaching mathematics activities (worksheet)	Teacher encouraged students (in teams) to draw the images of plane figures under enlargement from the origin for given scale factors on worksheets	✓		
Technological knowledge (TK_{ss})				
Demonstrating developed knowledge in spreadsheet skills	Entering and editing data in cells allowed for changes in the image size of a plane shape	✓		
Pedagogical content knowledge (PCK_{ABL})				
Applying ABL approach to stimulate students' interest in solving mathematics problem	Designed activities assisted students to find images of plane figures under enlargement from the origin for given scale factors	✓		
Technological pedagogical knowledge (TPK_{ABL})				
Engaging students in spreadsheet-based ABL activities	'Zooming' in and out allowed in-depth investigation and stimulated students' discussions on worksheet		✓	
Technological content knowledge (TCK_{ABL})				
Introducing fundamental mathematical concepts by spreadsheet incorporation	Changes in the scale factor (in the cells) allowed for demonstrations of a wide range of images (of given object) and immediate feedback making learners to concentrate more on mathematical relationships (of the scale factor, image and object size) rather the mechanics of construction		✓	
Technological pedagogical and content knowledge ($TPCK_{maths}$)				
Proper choice of spreadsheet technique in relation to mathematical concepts and ABL pedagogy	Spreadsheet allowed for determining how changes in the scale factor affect the orientation/size of the image providing a visual link between the object and changes in its image (giving students greater opportunity to consider general rules, test and reformulate and relationships among the scale factor (k), the object size and the image size on worksheet) ($TPCK_{maths}$)		✓	

(Cronbach's α = 0.86), the influence of computer use on instruction and Professional Enhancement (Cronbach's α = 0.79), the ability to improve professional practice by the use of computers. All sub-scales had a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*), with 1 as the lowest possible score representing a strong negative attitude, and 5 as the highest possible score representing a strong positive attitude. The TAC was administered before and after the course for all the participants (26 teams) of the study.

Table 5. Sample question for each TPACK knowledge type constructs.

Knowledge type	Sample question for each knowledge type	Cronbach's α pre	Cronbach's α post
TK_{ss}	I frequently play around with spreadsheets.	0.89	0.91
CK_{maths}	I have sufficient knowledge about mathematics.	0.84	0.83
PK_{ABL}	I can adapt ABL teaching style to different learners.	0.79	0.79
PCK_{ABL}	I know how to select effective ABL teaching approaches to guide student thinking and learning in mathematics.	0.70	0.69
TCK_{ABL}	I know about spreadsheet applications that I can use for understanding and doing mathematics.	0.84	0.81
TPK_{ABL}	I can choose spreadsheets application that enhance ABL approaches of a lesson.	0.83	0.85
$TPCK_{maths}$	I can teach lessons that appropriately combine mathematics concepts, spreadsheet applications and ABL teaching approaches.	0.88	0.91

Design team reports

Each design team maintained a record of activities and events occurring during the instructional technology course in a report. The report entries complemented findings from the other data collection instruments.

Data analysis

To analyse the data descriptive statistics, *t*-tests (paired and independent) and non-parametric statistics (Wilcoxon signed-rank test and Mann–Whitney *U*-test) were used. Effect size was calculated using Cohen's *d* (Cohen, 1988). Cohen (1988) provided tentative benchmarks for the interpretation of effect sizes. He considered $d = 0.2$ a small, $d = 0.5$ a medium and $d = 0.8$ a large effect size. Information recorded in the design team reports was analysed qualitatively using data-reduction techniques in which major themes (e.g. importance of collaboration; use of exemplary materials; learning technology by doing and challenges in instructional design in teams) were identified and clustered (Miles & Huberman, 1994).

Results

Lesson plans

The guides that the pre-service teachers had designed gave step-by-step instructions on how to set up the lesson environment; mainly showing the knowledge and skills needed to use spreadsheets (indicating TK_{ss}) in inputting data and viewing a plot of the data. For example, the study guide for the lessons in Enlargement and Statistics outlined:

> Set the cursor over cell X2 and cell Y2 to note the formulas. You should see: = k*X1 and = k*Y1 respectively. (The symbol * must be used for multiplication). (Enlargement)

> Highlight the cells that contain the data and use the chart command to create an x-y scatter plot in the second window, make sure to use the data from column 1 as x-data. (Statistics)

The lesson plan made links between the students' worksheet and the lesson activities of the pre-service teachers. Examples are:

> Guide students to carry out different activities with concrete objects to identify the images (by matching on their worksheet) of an object by a given vector. (PCK_{ABL}) (Plane Geometry)

> Alter the value of k (say k = 1, 2, 3, 4 etc.) and guide students to observe and record the sum of interior angles of the different polygons on their worksheet. (TPK_{ABL}) (Regular Polygons)

Analysis of the lesson plan documents also showed that specific roles were identified for teachers and students. Most lessons showed various tasks to be done by students (i.e. observing, recording, exploring etc.) while teachers were to guide and instruct during the lessons. For example:

> Begin with two linear graphs on the same axes on the spreadsheet and guide students to observe and record the values of x on their worksheet (as you alter the value of x) which satisfy the two equations simultaneously and their corresponding values of y. ($TPCK_{maths}$) (Simultaneous Linear Equations)

> Guide students to carry out different activities by organizing them in small groups … . (PK_{ABL}) (Matrices)

Comparing the lesson plans used for try-outs during the middle and end of the course shows that final lesson plans reflected clearly spelt-out lesson objectives (CK_{maths}), well-defined roles for both the teacher and students (PK_{ABL}) and well-mapped support of spreadsheet application techniques to student worksheet activities (TPK_{ABL}), as well as clearly defined use of the spreadsheet technique to stimulate student thinking in solving mathematics problems (TCK_{ABL}). This suggests that the insights learned by the pre-service teachers (feedback from peers and researcher) during their first teaching try-out served as necessary input for them in revising their design, as was reflected in the final teaching documents.

To further examine the impact of peer and researcher feedback on pre-service teachers' demonstration of TPACK in their lesson documents, the TPACK scores were compared with final lesson documents (which were not used in the teaching try-out). Table 6 shows the means and standard deviations between the lesson plans that were provided with mid-term feedback and those that were not.

The results indicate relatively high TPACK scores (with more TPACK codes) for lesson artefacts in which the pre-service teachers did peer teaching compared with artefacts in which no peer teaching was done. Although the lessons themselves were different topics, which seem to suggest a possible impact on the scores, the authors share a different view. First of all, the different criteria of the instrument itself focused on assessing how well the content of the various topics interconnected with the spreadsheet and the pedagogy and not mere TPACK occurrence (number of codes) in teachers' written lesson plans. Second, caution was taken to ensure the use of multiple coders in the analysis of the data sets to ensure that the instrument was reliable (the same argument holds for results shown in Table 8). It therefore appears that the specific feedback from peers and instructors and the authentic technology

Table 6. Descriptive statistics for end TPACK scores of pre-service teachers' lesson plan artefacts.

	Lessons (with peer teaching) (n = 8)			Lessons (without peer teaching) (n = 8)	
Lessons	TPACK score	#TPACK codes	Lessons	TPACK score	#TPACK codes
Enlargement	15.30	48	Pie chart	14.30	44
Statistics	16.70	54	Logarithmic functions	15.30	50
Simultaneous linear equations	16.00	48	Linear programming	15.30	43
Regular polygons	17.00	48	Modular arithmetic	14.70	44
Matrices	15.50	43	Quadratic functions	14.00	46
Straight lines	16.50	52	Trigonometry	14.90	46
Plane geometry	16.00	48	Bearings	15.00	44
Linear equations	18.00	54	Rotation	16.80	47
All lessons (mean)	16.38	395	All lessons (mean)	15.03	362

Note. Minimum score = 7, maximum score = 21.

experience itself as a result of the hands-on teaching try-out are the possible reasons for the improved scores of pre-service teachers who taught their peers.

Lesson enactment

As was observed in their lesson enactment, the eight teams of pre-service teachers who taught their peers at mid-term (referred to hereafter as peer teachers, PT) and also at the end of the course used their lesson plans to guide class instruction using 'interactive demonstration' in a spreadsheet environment. The use of the spreadsheet gave students greater opportunities to verify results and consider general rules, make links between spreadsheet formulae, algebraic functions and graphs, and analyse and explore number patterns and graphs within a shorter time. The analysis showed that the PTs used the spreadsheet environment and the student worksheet to engage their students in different learning-related activities. Table 7 shows the added value of spreadsheet use in different lessons to engage students in different learning activities.

The PTs, however, found great difficulty in using the spreadsheet to develop mathematical concepts well enough to support their students' understanding, especially during the mid-term (first teaching try-out lessons). For instance, it was difficult to illustrate that as the absolute value of m increases, the graph of $y = mx + k$ becomes steeper and vice versa in the lesson on linear equations. Apparently, what was difficult for the students was to connect the resulting changes in the graph (which is wider or steeper?) to changes in the numerical values (PTs displayed graph after graph on the same spreadsheet when the parameters were altered). In the lesson on straight lines, it was a struggle for students to read coordinates of the mid-point of a line segment joining two given points from the spreadsheet on the slides. As a result, these PTs were compelled to read out the values while students did the

Table 7. Activity-based lessons with the added value of spreadsheets.

Lesson	Teaching and learning activities	Added value of spreadsheet use
Polynomial Functions *(Year 2)*	Collaboration in teams to explore patterns, team presentations and peer assessment	Changing variables in cells (spreadsheet environment) (TK_{ss}), a wide range of examples of graphs were demonstrated without having to draw them physically (TCK_{ABL}); learners explored many cases using their worksheet in a shorter time (PK_{ABL}), giving them greater opportunity to consider general rules, test and reformulate hypotheses (PCK_{ABL}).
Plane Geometry *(Year 1)*	Interactive demonstration with students, collaboration in teams to explore relationships/properties of figures	Technology use in an interactive demonstrative lecture stimulated students' discussions with worksheets (TPK_{ABL}). Visual representations of geometrical figures allowed for immediate feedback (TCK_{ABL}), allowing learners to concentrate more on mathematical relationships rather than on the mechanics of construction (TCK_{ABL}).
Statistics *(Year 2)*	Students view presentation, make predictions, collect data and interpret them in teams	Using the spreadsheet allowed for many numerical calculations simultaneously (TCK_{ABL}), easy tabulation of numerical data, graphical representation of the data, analyses and exploration of number patterns (CK_{maths}).
Simultaneous Linear Equations *(Year 1)*	Interactive demonstration with students, group tasks and group presentations	Spreadsheet allowed for solving equations numerically and graphically providing a visual link between algebraic solution for the intersection of two straight lines and their graphical representation (making it easy for students to match them on worksheet) ($TPCK_{maths}$); 'zooming' in and out (TK_{ss}), allowed in-depth investigation of points of intersection (TPK_{ABL}).

recording on their worksheets. Another problem observed during the lesson on simultaneous equations was the difficulty students encountered in verifying graphical solution sets (from the spreadsheets) of two linear equations in two variables. The graphical solution sets appeared approximated and in most cases did not match answers from the students' algebraic solutions of the same set of equations. Similar difficulties were encountered in the other lessons as well. The corresponding subsequent lessons implemented at the end (second teaching try-out) of the course were less of a struggle. For instance, on linear equations, the teacher was able to present the concepts better by demonstrating the different graphs with corresponding changing values of the parameters on the same spreadsheet. Zooming out on the coordinates of mid-points was an improved way to allow students read and record their own values during the lesson on straight lines, and using the 'Increase decimal' button on the spreadsheet helped to show more precise values to verify algebraic solution sets in the lesson on simultaneous equations.

In spite of challenges, the analysis of the lesson observations at the end of term suggests that the PTs' knowledge and skills developed and improved more than their counterparts without peer teaching experience (further referred to as pre-service teachers without peer teaching, NPTs) (Table 8). The relatively high TPACK scores of the PTs suggest that the results and insights (feedback from peers and researcher) learned from the first teaching try-out as well as authentic technology experienced gained from the teaching might have served as necessary inputs for the PTs in revising and implementing their designs in the second try-out.

Pre-service teachers' perceived TPACK knowledge and skills

Pre-service teachers' perceived TPACK knowledge and skills were measured on a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) about teachers' self-efficacy toward technology use. The scores are interpreted as follows: 1 is the lowest possible score, which represents very strong negatively perceived TPACK knowledge and skills, while the 5 is the highest possible score, which represents a very strong positive response. The questionnaire was administered twice: before and after the course.

Teachers' responses in the pre–post survey delineate expressed their disposition toward the various knowledge domains: CK_{maths}, PK_{ABL}, PCK_{ABL}, TK_{ss}, TPK_{ABL}, TCK_{ABL}, $TPCK_{maths}$.

A paired sample *t*-test showed significant ($p < 0.0001$) difference in all subscales. This seems to suggest that the pre-service teachers' knowledge and skills improved during the course. To compare the development of TPACK for the two categories: PT and NPT (8 teams consisting of 32 pre-service teachers each), an independent *t*-test of TPACK post-test scores was conducted. The results showed

Table 8. Descriptive statistics for end TPACK scores of pre-service teachers' lesson observation.

Lessons (with peer teaching) (*n* = 8)	TPACK score	Lessons (without peer teaching) (*n* = 8)	TPACK score
Enlargement	41.81	Pie Chart	40.10
Statistics	42.29	Logarithmic Functions	40.00
Simultaneous Linear Equations	43.10	Linear Programming	41.00
Sum of Interior Angles	43.50	Modular Arithmetic	41.05
Matrices	41.61	Quadratic Functions	40.40
Straight Lines	41.39	Trigonometry	39.54
Plane Geometry	42.00	Bearings	41.00
Linear Equations	43.40	Rotation	41.20
All lessons	42.39	All lessons	40.54

Note. Minimum score = 20, maximum score = 60.

Table 9. Perceived TPACK knowledge and skills for NPTs and PTs.

Factor	PT (n = 32) Mean (SD)	NPT (n = 32) Mean (SD)	P	Effect size
TK_{ss}	4.13 (0.301)	4.41 (0.399)	0.005*	0.79
CK_{maths}	4.44 (0.577)	4.52 (0.400)	0.049*	0.15
PK_{ABL}	4.33 (0.322)	4.50 (0.430)	0.027*	0.45
PCK_{ABL}	4.36 (0.459)	4.48 (0.552)	0.031*	0.24
TCK_{ABL}	4.10 (0.309)	4.34 (0.410)	0.008*	0.67
TPK_{ABL}	4.21 (0.291)	4.45 (0.309)	0.001*	0.80
$TPCK_{maths}$	4.15 (0.277)	4.43 (0.340)	0.001*	0.90

*Significant at the 0.05 level.

that significant differences exist in mean scores in all constructs in favour of the pre-service teachers who did a teaching try-out with peers.

It appears the peer teaching experience in which pre-service teachers engage themselves in additional planning and preparation informed their knowledge and skills in the different knowledge domains, especially in spreadsheet-related constructs.

Pre-service teachers' attitudes toward technology

A paired sample t-test result indicated significance differences ($p < 0.0001$, $d = 0.80$) in overall computer attitudes (pre: $M = 4.10$, SD = 0.370) (post: $M = 4.39$, SD = 0.352) of pre-service teachers before and after the course. Comparing the attitudes between the two groups of participants (PT and NPT), no significance difference in overall computer attitudes (peer teaching $M = 4.37$, without peer teaching $M = 4.32$) between the two groups was found.

Contribution of the instructional technology strategies to the development of pre-service teachers' technology integration competencies

Both PTs and NPTs considered the contribution of all the strategies important in developing their technology integration competencies. However, pre-service teachers who did a teaching try-out with peers stressed the usefulness of feedback from peers and instructors in revising their lessons to develop their TPACK. This seem to suggest that the authentic technology experience PTs acquired during the teaching try-outs including feedback on lessons, made a significant difference to their TPACK development much more than for their NPT counterparts, who did not have that experience.

Despite appreciating the importance of the strategies in the instructional technology course and the role they played in enhancing their TPACK, the teachers admitted encountering some challenges in the instructional design process. They reported that although the opportunity to *learn technology by doing* was a useful strategy, they highlighted having encountered some difficulty in applying their own abilities in an unknown skill domain as novice teachers in technology use. As a result, most teams reported adopting strict use of the exemplary materials, which could have hindered their own creativity in the design process. Other problematic and difficult areas they reported having experienced during the design of their lesson include: designing authentic learning activities for their chosen topics, selecting and matching appropriate integrating spreadsheet tools and relevant resources in designing mathematics learning activities. For example in one report (from NPT), the team indicated:

> Our first and second meetings to design our lesson on Polygons were held on 17th and 24th of February. In both meetings we had problems designing spreadsheet activities to determine the sum of interior angles so we had to reschedule the meetings. In our next meeting which was on the 28th, the group agreed to change the topic of *Rotation*...

The issue of time and punctuality at design meetings was also reiterated. Again, different views among members within teams posed challenges during lesson designs and discussions. However, they indicated solving such problems through discussions and negotiations.

The results reported here seem to point to a major outcome of the study being the construction of a body of design strategies that could be used to guide efforts in future developments of pre-service teachers' experiences in technology integration. The following section throws more light on this discussion.

Discussion

The study addressed the question: *How do the strategies applied in the mathematics instructional course have an impact on pre-service mathematics teachers' technology competencies?* The impact of the course on the pre-service teachers' competencies is reflected in their increased attitude towards technology, self-reported TPACK development, and their lesson plans and lesson implementation. The study has shown that both groups of pre-service teachers (PT and NPT) developed and improved their competencies in the course, however the evidence showed that pre-service teachers involved in the mid-term teaching try-out developed their competencies much better. One obvious reason for developed and improved competencies (particularly with the PTs) is the pedagogical integration of technology experience (which promoted more hands-on experience) they acquired during the teaching try-out; these pre-service teachers engaged themselves in additional planning and preparation needed to teach the technological lessons. This is consistent with other studies (e.g. Barton & Haydn, 2006; Tearle & Golder, 2008) that acknowledge the importance of applying teachers' competencies about technology integration in authentic settings. The contribution of feedback from peers and instructors during the try-outs was an added advantage for improved competencies of PTs. The study also has demonstrated that several other strategies used in the course accounted for developed and improved technology integration competencies of the pre-service teachers. It seems that observing an instructor using technology is an important motivator for the pre-service teachers (both groups) to integrate technology into their own practices (e.g. Haydn & Barton, 2007). Consistent with research studies (e.g. Voogt, 2010), the pre-service teachers indicated that the exemplary materials provided them with theoretical and practical insights of technology-supported learner-centred lessons and hands-on experience. Pre-service teachers also acknowledged the importance of collaborative design teams in stimulating and enhancing their TPACK throughout the programme. According to them, collaborative experiences provided them with opportunities to explore and practise technology application in a supportive environment consistent with previous studies (e.g. Angeli & Valanides, 2009). Again, the pre-service teachers reported that the opportunity to *learn technology by* *doing* offered in the course was a useful strategy in developing their TPACK. Finally, the programme, which combined a mixture of short lectures and practical work, was a good approach to sustain pre-service teachers' interest and focus in developing their competencies. In this respect, it seems to be important that pre-service teachers have the possibility to see and experience the pedagogical integration of technology in the classroom during their training experiences, by observing good examples and being able to implement such practices themselves (Enochson & Rizza, 2009).

Pre-service teachers also experienced some difficulties applying their knowledge and skill in designing spreadsheet-supported lessons in the course. As novice teachers in technology, they experienced difficulty applying their own abilities in an unknown skill domain during the instruction design. As a result, some teams made extensive use of the exemplary materials (replicating the instructor's example with slight changes). This action has the tendency to reduce PSTs' opportunity to construct their own technology-based lessons. Other areas they identified to be particularly challenging and difficult included: selecting and integrating appropriate spreadsheet tools and relevant spreadsheet applications in designing authentic learning activities for selected topics.

In spite of the drawbacks, the mathematics instructional technology course, introduced in the study to develop pre-service teachers' technology integration competencies, is still ongoing and has been made part and parcel of the curriculum in the teacher education programme at the University of Cape Coast. This is the essence of a research study; to ensure that after design and implementation, the innovation will continue in the educational institution. The challenge, however, that may confront this reform may be twofold: to extend the strategies applied in the mathematics instructional technology course to future pre-service teachers in the University of Cape Coast and to advocate its use for future initiatives in other teacher education programmes in Ghana and sub-Saharan Africa.

That notwithstanding, the study provides useful guidelines for implementing strategies in the design of a subject-specific teacher education programme which prepares pre-service teachers to integrate technology in teaching. The study reiterates that in replicating such an arrangement in Ghana or a similar context, programme designers should deliberately create experiences which have the following:

- exemplary curriculum materials are an important means as they can inspire teachers to learn and provide a 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 concrete how-to-do suggestions and facilitate a better implementation of ICT-based innovations;
- collaborative design teams, in which pre-service teachers work with peers, are an important means to stimulate and support teacher learning. This approach of ICT integration will improve interaction and interdependence among pre-service teachers; making them discover how to share knowledge and ideas as well to brainstorm on relevant information relating to their designs;
- scaffolds and authentic technology experiences, such as teaching try-outs with peers, are integrated parts of the 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, scaffolds are provided. In instances where large classes hinder the implementation of teaching try-outs for all participants (such as in the context of Ghana), micro-teaching within teams should be encouraged;
- an orientation programme for pre-service teachers will provide a learning experience where conceptual and theoretical information could be linked to a practical application. For more effective collaboration with the use of the exemplary materials and working in design teams, such an orientation programme is important;
- opportunities where teachers can learn technology by design would be created.

Conclusion

The study demonstrated that all the strategies accounted for developing and improving technology integration competencies, but scaffolding *authentic technology experiences* including feedback from teaching try-outs played the most significant contribution to pre-service teachers' development of technology integration competencies. The importance of authentic teaching experiences with technology contributes to the reduction in pre-service teachers' anxieties, thereby increasing their enthusiasm to use technology in instruction. The study also showed that observing an ICT-based lesson being modelled is an important motivator for pre-service teachers to integrate technology into their own practices (cf. Haydn & Barton, 2007), however caution should be taken to ensure that such exemplary lessons provide meaningful and effective technology examples. Secondly, over-reliance on exemplary materials can ruin the creative thinking of pre-service teachers to construct their own ICT-based lessons, since they will tend to replicate what has been designed and modelled to them.

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