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## Pre-service mathematics teachers' learning and teaching of activity-based lessons supported with spreadsheets

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In this study, 12 pre-service mathematics teachers worked in teams to develop their knowledge and skills in using teacher-led spreadsheet demonstrations to help students explore mathematics concepts, stimulate discussions and perform authentic tasks through activity-based lessons. Pre-service teachers' lesson plans, their instruction of the lessons designed, experiences and lesson enactment outcomes were examined. The pre-service teachers in the study were able to develop and demonstrate their knowledge and skill adequately in designing and enacting activity-based mathematical lessons supported with spreadsheets. The results also showed that the pre-service teachers' use of the spreadsheet as an instructional tool promoted student in-depth mathematical concept formation and an activity-based learning approach to make lessons less teacher centred and more interactive.

**Keywords:** technology integration; activity-based learning; technological pedagogical content knowledge; student learning outcomes; mathematics teacher education; spreadsheets

### Introduction

In Ghana, mathematics is a required subject at all levels in pre-university education. Owing to this importance, the government is committed to ensuring the provision of high-quality mathematics education. Various attempts have been made in the past to improve its success in schools. In spite of government efforts, learning mathematics has not undergone much change in terms of how it is structured and presented and has resulted 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 these low achievements. The most frequently used strategy in mathematics classrooms is the teacher-centred (chalk and talk) approach (Ottevanger et al., 2007; Agyei & Voogt, 2011a), in which teachers do most of the talking and intellectual work, while students are passive receptacles of the information provided. This type of teaching is heavily dominated by teachers (while students are silent), and involves whole-class teaching, lots of notes being copied and hardly any hands-on activities, and where teachers rush to cover all the topics

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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). Although these teacher-centred approaches still dominate in mathematics classrooms, curriculum and policy documents in this context suggest student-centred constructivist teaching methods in which learners construct and internalise new knowledge from their experiences (Ministry of Education, 2000). For example, the new curriculum in mathematics at the senior high school places emphasis on skill acquisition, creativity and the arts of enquiry and problem solving (Ministry of Education, Science and Sports, 2007), but many teachers in Ghana do not have the background knowledge and proper skill set to teach mathematics in this way.

Keong, Horani, and Daniel (2005) recommended a constructivist pedagogical approach in teaching mathematics and explained that such an approach is easily supported by technology, where students use technology to explore and reach an understanding of mathematical concepts by concentrating on problem-solving processes rather than on calculations related to the problems. So and Kim (2009) indicated that technology can play a critical role in representing subject matter to be more comprehensible and concrete, helping students correct their misconceptions on mathematical concepts, providing cognitive and metacognitive scaffolding and ultimately improving learning outcomes. Other studies (e.g. Beauchamp & Parkinson, 2008; Bottino & Robotti, 2007) have reported positive effects of incorporating technology in teaching mathematics to enhance motivation and improve student achievement. In spite of the numerous advantages that come with technology, many maths teachers do not feel proficient in teaching mathematics lessons that take advantage of technology-rich environments (Niess, 2008). Technology simply being present in the classroom is not enough (National Council of Teachers of Mathematics, 2000), and the use of technology ultimately is the responsibility left to mathematics teachers. But integrating technology in teaching mathematics is a very complex and difficult task for mathematics teachers. They have to learn to use new technologies appropriately and to incorporate them in lesson plans and lesson enactment (Mishra & Koehler, 2006). 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.

This study enhanced a professional development arrangement in which pre-service teachers collaboratively designed and used technology-supported lesson teaching materials in mathematics instruction, in spite of limited technological accessibilities in the context. In the study, the pre-service teachers use technology as an instructional tool in an 'interactive demonstrative' lecture to enact a guided activity-based pedagogical approach (referred to as activity-based learning) in teaching mathematical concepts.

### **Activity-based learning (ABL) in mathematics**

According to Mayer (2004), a common interpretation of the constructivist view of learning as an active process is that students must be active during learning. Furthermore, he explains that constructivist learning requires active teaching methods such as group discussions, hands-on activities and interactive games. The use of the ABL pedagogical approach in this research context, like other student-centred pedagogies,

has been motivated by recognition of the failures of traditional instruction (Ottevanger et al., 2007) and is in line with the constructivist premise to make learning an active sense-making process. Unlike traditional instruction, ABL actively engages the student in constructing knowledge. 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 believed 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. Mayer (2004) emphasised guidance, structure and focused goals when using an activity-based learning approach and recommended using guided discovery, a mix of direct instruction and hands-on activity, rather than pure discovery. Hmelo-Silver Duncan, and Chinn (2008) indicated that such guided inquiry approaches are not substituting content for practices; rather they advocated that content and practices are central learning goals. Hmelo-Silver et al. (2008) argued that while it is challenging to develop instruction that fosters the learning of both theoretical frameworks and investigative practices of a discipline, such approaches provide the learner with opportunities to engage in scientific practices of questioning, investigation and argumentation as well as learning content. This study engaged pre-service teachers to develop the knowledge and skills needed to design and enact ABL lessons as a strategy for teacher learning and professional development. Although the environment did not provide students with opportunities for innovative use of technology themselves (e.g. through hands-on activities), the expectation was that the pre-service teachers will be able to apply their knowledge growth in teaching knowledge and skills in enacting ABL lessons by employing a mix of direct instruction and technology-enhanced, teacher-led demonstrations to guide students through activities (via student worksheets) to enhance their learning.

### **TPACK and mathematics**

According to Niess, van Zee, and Gillow-Wilese (2010–11), most teachers learned mathematics using paper and pencil, which limited the use of data for exploration and required time to calculate averages and create charts for every change in the variables. With the potential of technologies in maths education, however, there is a need for teachers to create innovative learning experiences that truly engage the power of technology to involve students in higher order thinking tasks. Thus, mathematics teachers are still confronted with challenges and questions of how and when to incorporate such technologies for teaching and learning various subject matter topics (Niess, 2011). For this reason, teachers' knowledge and skills for teaching with technology need to be developed (Niess, 2008). Mishra and Koehler outlined the Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2008; Mishra & Koehler, 2006) in an effort to explain the types of knowledge teachers need to integrate technology into their teaching. TPACK emphasises the comprehensive set of knowledge and skills teachers need to successfully integrate technology in their instructional practice (Koehler & Mishra, 2008). Niess (2011) indicated that TPACK strategic thinking includes knowing when, where and how to use domain-specific knowledge and strategies for guiding students' learning with appropriate information and communication technologies. Considering the goal of engaging students in mathematical problem solving, for example, a mathematics

teacher's TPACK must focus on thinking strategically in planning, organising, implementing, critiquing results and abstracting plans for specific mathematics content and diverse student needs (Niess, Sadri, & Lee, 2007). This framework explicitly acknowledges that effective pedagogical uses of technology are deeply influenced by the content domain in which they are situated. Thus, the TPACK framework for using technology strategically in classroom instruction does not encourage technology as being a 'stand alone' support to mathematics teacher education but as a tool specifically and uniquely applied to mathematics instruction. Subject-specific technological software such as spreadsheets has been used as a pedagogical tool for teaching and learning and has depicted potential which effective teachers can maximise to develop students' understanding and increased proficiency in mathematics. Niess et al. (2010–11) indicated that spreadsheets contain features for modelling and analysing change, providing teachers with tools that rely on mathematics concepts and processes for accurate analysis. According to Niess et al. (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 of 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. This redirection exposes the importance of teachers' strategic thinking and actions with respect to integrating technologies as learning tools in mathematics instruction. In this study, TPACK has been used as a conceptual framework to examine the knowledge and skills pre-service mathematics teachers developed about technology, pedagogy and content as they designed and enacted activity-based lessons supported with spreadsheets. As shown in Figure 1, the pedagogical knowledge examined in this study was ABL ( $PK_{ABL}$ ). The technological knowledge ( $TK_{ss}$ ) learned by the pre-service teachers were spreadsheet applications for mathematics, because these were readily available in senior high schools and in teacher education colleges (Agyei & Voogt, 2011a, b), were user-friendly and had the potential to support students' higher order thinking in mathematics (Agyei, 2012; Niess et al., 2007). Content knowledge ( $CK_{maths}$ ) was mathematics which was the pre-service teachers' teaching subject area.

### **The professional development arrangement**

The professional development arrangement was based on 'learning technology by design' (Mishra & Koehler, 2006) and has been described extensively in Agyei (2012). In the professional development, pre-service teachers collaboratively designed and enacted spreadsheet-supported ABL lessons. The professional development consisted of three stages: an introductory workshop for design teams, design of lessons in design teams and implementation of lessons by design team members. The workshop lasted for two weeks and required pre-service teachers to attend lectures lasting between one and two hours and laboratory sessions lasting between two and three hours, per day. The lectures were intended 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 and appraised by an expert) were taught by the researcher in a teacher-led spreadsheet demonstration and discussed in class during

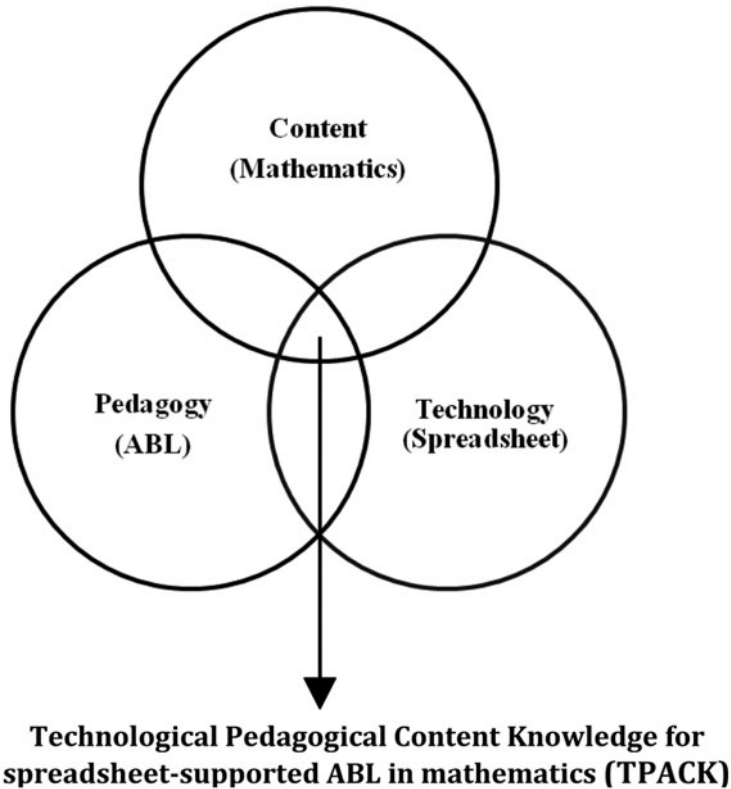


Figure 1. Framework of TPACK for this study.

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 taught aspects of the model lessons, and worked on their assignments and project.

Based on their experiences, the pre-service teachers worked in teams of two to develop and model their own lessons (in suitable mathematics topics from the senior high school curriculum) based on the exemplary material; identified appropriate spreadsheet applications for the topic; designed and developed appropriate learning activities based on ABL and incorporated activities in their lesson plans. Micro-teaching practice, in which teams tried out their designs among themselves, was a necessary component in this stage. The design phase lasted for six weeks, spanning a period of three hours on average for each day. In the implementation stage (five weeks) the teams enacted their lessons two times each at different stages: among their peers at the teacher education programme and in three senior high schools. Consequently, six activity-based lessons supported with spreadsheets were developed. Table 1 gives an overview of the lessons designed and enacted by the pre-service teachers at the different stages during the implementation phase.

Column 1 shows the number of student teachers in each lesson during the peer teaching. Columns 2, 3 and 4 show the three senior high schools, the levels in which

Table 1. Overview of lessons designed and taught by the pre-service teachers.

Lesson	Peer teaching <i>N</i>	Actual classroom try-outs (SHS)			Lesson duration (mins)
		School	Form	<i>N</i>	
Transformation by a Vector (TBV)	30	B	3	35	80
Distance between two given points of a line (DBTGP)	32	A	1	43	40
Trigonometric Functions (TRIG)	32	C	3	42	80
Quadratic in Vector Form (QVF)	34	B	2	36	80
Quadratic in Polynomial Form (QPF)	31	A	2	44	80
Graphs of Linear Equations (GLE)	31	C	1	25	40

the lessons were taught and the number of senior high school students involved in each lesson, respectively. The lesson column shows the duration of each lesson taught.

Each lesson document comprised a teachers' support or guide to help set up the environment, a plan for lesson implementation and a student worksheet, which promoted hands-on activities during lesson implementation. All lessons were taught in a classroom with a computer and an LCD projector, which aided the pre-service teachers in their spreadsheet demonstrations. The researcher acted mainly as a facilitator, coach and observer at different stages of the study.

### Research questions and research design

The main research question of the study was: To what extent did pre-service teachers' knowledge and skill in designing and enacting spreadsheet-supported ABL lessons develop and influence their experiences and lesson outcomes? The following sub-research questions guided the study:

- (1) To what extent did pre-service teachers demonstrate the knowledge and skills needed to design and enact spreadsheet-supported ABL lessons in mathematics?
- (2) How did pre-service teachers perceive their own development in the knowledge and skills needed to design and enact spreadsheet-supported ABL lessons in mathematics?
- (3) To what extent did pre-service teachers' design and enactment of spreadsheet-supported ABL lessons impart on their experiences and lesson outcomes?

This study was an in-depth investigation of the knowledge and skill needed to design and enact spreadsheet-supported ABL lessons of pre-service mathematics teachers in which both quantitative and qualitative data were used.

### Methods

#### *Participants*

Twelve pre-service mathematics teachers participated in the study. The pre-service teachers were in their final year of the mathematics teacher education programme at

University of Cape Coast in Ghana. The four-year teacher training programme allows pre-service teachers to teach at junior and senior high school when they graduate. The average age of these pre-service teachers was 26 years. These pre-service teachers are novices regarding the use of technology to teach or learn mathematics. 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 and 3) were taught lessons by the pre-service teachers.

### ***Instruments***

While TPACK is often assessed on a more generic and abstract level measuring perceived knowledge which is not tailored towards specific content knowledge, specific pedagogical knowledge or specific technological knowledge, the instruments described in this study were adapted to focus on specific spreadsheet applications in enacting a guided, activity-based, pedagogical approach to develop pre-service teachers' TPACK (i.e. knowledge and skill) in teaching mathematics. In the study, pre-service teachers' knowledge and skills which are needed to teach spreadsheet-supported ABL lessons in mathematics were operationalised as their TPACK, and consist of the following specific knowledge and skills:

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

Table 2 presents an overview of the data-collecting instruments measuring how pre-service teachers perceive as well as demonstrate their knowledge and skill and the impact on their experiences and lesson outcomes for the activity-based lessons supported with spreadsheets.

### ***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 pre-service teachers' written lesson plans. While TIAR is a general rubric to determine TPACK in lesson plans, adaptations were made to fit to TPACK for spreadsheet-supported ABL in mathematics. The rubric consisted of seven different criteria and were scored as: *not at all* (1), *minimal* (2) and *strong* (3). Interrater



Table 2. Pre-service teachers' knowledge and skill learning and classroom practices.

Research questions	Instruments				
	Lesson plan rubric	Observation rubric	TPACK survey	Teacher interview	Researcher's logbook
RQ1	✓ (post)	✓ (post)			✓
RQ2			✓ (pre-post)	✓ (post)	
RQ3				✓ (post)	✓

reliability (Cohen's  $\kappa = 0.91$ ) was calculated using a sample of three lesson plans by two raters. The lessons were first coded (based on the TPACK constructs) and then assessed using the rubric.

#### *TPACK observation rubric*

The observation rubric was adapted from a valid and reliable TPACK-based Technology Integration Observation Instrument (Hofer, Grandgenett, Harris, & Swan, 2011), which was developed and used to assess TPACK in observed instruction. Adaptations were made so that TPACK could be observed 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). The interrater reliability (Cohen's  $\kappa$ ) assessed for two observed lessons was  $\kappa = 0.94$ . Table 3 gives an overview of sample items for each TPACK knowledge-type construct that was assessed in lesson three (TRIG).

#### *Pre-service teachers' TPACK questionnaire*

The questionnaire included items that addressed the pre-service teachers' self-efficacy of their TPACK, adapted from Schmidt et al. (2009) on a 5-point Likert scale format (from 1 = *strongly agree* to 5 = *strongly disagree*). The instrument was adapted and administered two times, before and after the intervention. Sample questions for each TPACK knowledge type include: I frequently play around with spreadsheets (TK<sub>ss</sub>), I have sufficient knowledge about mathematics (CK<sub>maths</sub>), I can adapt ABL teaching style to different learners (PK<sub>ABL</sub>), I know how to select effective ABL teaching approaches to guide student thinking and learning in mathematics (PCK<sub>ABL</sub>), I know about spreadsheet applications that I can use for understanding and doing mathematics (TCK<sub>ABL</sub>), I can choose spreadsheet applications that enhance ABL approaches of a lesson (TPK<sub>ABL</sub>), I can teach lessons that appropriately combine mathematics concepts, spreadsheet applications and ABL teaching approaches (TPCK<sub>maths</sub>).

Teachers' responses in the pre-post survey delineated their own development in the perceived knowledge and skills needed to design and enact spreadsheet-supported ABL lessons.

Cronbach's alpha reliability estimates of this instrument range from 0.75 to 0.93 (Schmidt et al., 2009). Since Schmidt et al.'s (2009) instrument assessed TPACK on a more generic level, questions on whether the pre-service teachers will develop TPACK in similar initiatives with explicit focus on ABL use and spreadsheets in particular in the teaching of mathematics content could be raised. The authors

Table 3. Sample items for each TPACK knowledge-type construct.

Sample items	Example of observed or partly observed practice	3	2	1
<b>Subject matter (CK<sub>maths</sub>)</b>				
Clearly introducing mathematics topic and learning goals of lesson	Teacher assisted students to form the concept of negative angles and to establish the following relations: $\sin(-\theta) = \sin(360^\circ - \theta) = -\sin(\theta)$ $\cos(-\theta) = \cos(360^\circ - \theta) = \cos(\theta)$ $\tan(-\theta) = \tan(360^\circ - \theta) = -\tan(\theta)$	✓		
<b>Pedagogical knowledge (PK<sub>ABL</sub>)</b>				
Engaging students in solving authentic problems using teaching mathematics activities (worksheet)	Teacher encouraged students (in teams) to use calculators and specific values from (worksheet) to verify trigonometric solutions.	✓		
<b>Technological knowledge (TK<sub>ss</sub>)</b>				
Demonstrating developed knowledge in spreadsheet skills	Entering and editing data in cells allowed for changes in the graphs.	✓		
<b>Pedagogical content knowledge (PCK<sub>ABL</sub>)</b>				
Applying ABL approach to stimulate students' interest in solving mathematics problem	Designed activities assisted students to find solutions to trigonometric equations giving them greater opportunity to consider general rules test and reformulate hypotheses.	✓		
<b>Technological pedagogical knowledge (TPK<sub>ABL</sub>)</b>				
Engaging students in spreadsheet-based ABL activities	'Zooming' in and out allowed in-depth investigation and stimulated students' discussions on worksheet.		✓	
<b>Technological Content knowledge (TCK<sub>ABL</sub>)</b>				
Introducing fundamental mathematical concepts by spreadsheet incorporation	Spreadsheet representations of trigonometric functions allowed for demonstrations of a wide range of graphs and immediate feedback making learners concentrate more on mathematical relationships rather than on the mechanics of construction.		✓	
<b>Technological Pedagogical and Content Knowledge (TPCK<sub>maths</sub>)</b>				
Proper choice of spreadsheet technique in relation to mathematical concepts and ABL pedagogy	Spreadsheet allowed for investigating the nature of graphs of trigonometric functions and graphically providing a visual link between graphs of trigonometric functions and their solution sets (making it easy for students to match graphs of trigonometric functions and their solutions on worksheet) (TPCK <sub>maths</sub> ).			✓

suggest that once pre-service teachers understand their context-specific strategies and representations in which new technologies are integrated (cf. Harris, Mishra, & Koehler, 2009; Koehler, Mishra, & Yahya, 2007), the instrument is likely to be valid and reliable within the context of the study.

Again, caution has been taken to ensure that results reported were honest and accurate, reflecting valid scientific conclusions without biases. For example, careful steps were taken to ensure triangulation through the use of multiple data sources; multiple data methods and involvement of multiple coders (cf. Cohen, Manion, & Morrison, 2007) in the analysis of qualitative data to ensure validity and reliability of results. Thus, although findings do not allow for broad generalisations owing to the limited scope and specific context, they provide information about conditions and opportunities of developing experiences of teachers' integration of ICT in the teaching and learning in senior high schools in Ghana.

### *Teacher interviews*

To explore pre-service teachers' knowledge and skills needed to design and enact spreadsheet-supported ABL, semi-structured interviews were conducted for each pre-service teacher after his/her teaching session. The interview schedule instrument consisting of 10 items was designed by the researcher to cover the themes: usefulness of spreadsheet-supported ABL lessons, experiences with spreadsheet-supported ABL lessons, lesson design challenges and lesson enactment challenges of activity-based lessons supported with spreadsheets. The interviews were transcribed and coded using the theme as coding schemes. Two raters coded the interview data using a sample of five interviews (from five pre-service teachers). The interrater reliability (Cohen's  $\kappa$ ) was  $\kappa = 0.92$ .

### *Researcher's logbook*

The researcher's log book was used to maintain record of activities and events occurring during the design and enactment of the activity-based lessons supported with spreadsheets. The logbook entries complemented findings from the other data collection instruments. Information recorded in the logbook was analysed qualitatively using data reduction techniques in which major themes (students' participation; pre-service teachers' role; use of lesson materials and challenges in enacting activity-based lessons supported with spreadsheets) were identified and clustered (Miles & Huberman, 1994).

## **Results**

### ***Lesson plans***

The teacher's support or guide gave step-by-step instructions on how to set up the environment (before a lesson is conducted), mainly regarding knowledge and skills about use of spreadsheets (TKss) in inputting numerical data and viewing a plot of the data. For example, lessons in GLE and QPF outlined:

Define the values of  $m$  as 1 and  $k$  as 0 in cells **B4** and **B5** respectively. (This is done by clicking in cell **B4** ...). (GLE)

Make up an equation in the form  $y = a*(X1)^2 + b*(X1) + k$ , and enter the formula in cell **Y1** (or in the first cell of the next column you chose). Then use the Fill Down command ... (QPF)

The lesson documents made links between the students' worksheet and the activities on the lesson plan to be implemented by the pre-service teachers. Examples are:

In this activity, ask students to indicate (by tick (✓)) the features of the equations as shown on the Worksheet (without plotting or solving them). (PCK<sub>ABL</sub>) (QVF)

Set the value of  $m$  to be zero and continue decreasing the value of  $m$  in the cell to negative numbers as students record the changes in the graph on their worksheet. (TPK<sub>ABL</sub>) (DBTGP)

Analysis of the document also showed that specific roles were identified for the pre-service teachers as well as the students. Most lessons showed various tasks to be done by students (i.e. observing, recording, exploring etc.) while pre-service teachers were to guide and instruct during the lesson. These were enumerated in the various lessons:

Get students to observe how the graph changes when  $a$  is altered on the spreadsheet. (TPCK<sub>maths</sub>) (QVF)

Begin with the graph of the standard function:  $y = x$  on the spreadsheet and guide students to observe and record how the graph changes when  $m$  changes. (TPCK<sub>maths</sub>) (GLE)

Prepare students for the following activities (Activities: 1.0 – 3.0) by organising them in small groups ... . (PK<sub>ABL</sub>) (TBV)

The results of the analysis of the lesson plans are presented in Table 4. The highest number of codes (Cds) for TPACK (per lesson) was found in CK<sub>maths</sub> (12) with the total number of codes (TCds) being 67. The analysis showed fairly high TPACK evidence in the pre-service teachers' lesson plan documents with the highest mean scores in PK<sub>ABL</sub> (2.56, 0.131) and CK<sub>maths</sub> (2.53, 0.084) and the lowest mean scores in TPK<sub>ABL</sub> (2.42, 0.028).

### ***Lesson enactment***

During lesson enactment, the pre-service teachers used their lesson plans to guide class instruction in a teacher-led demonstration in a spreadsheet environment. All pre-service teachers introduced and developed fundamental concepts using spreadsheet demonstrations with which they gradually engaged their students to develop higher concepts as lessons progressed. The approach provided students with learning experiences in which they were able to fall on the uniqueness of the teacher-led spreadsheet demonstrations to develop their ideas (via activities on the worksheet) in the higher order thinking task. For instance in the QVF lesson pre-service teachers were able to demonstrate a wide range of examples of graphs by changing variables in cells (on the spreadsheet) without having to draw them physically; learners were able to see many graphs in a shorter time, giving them greater opportunity to consider general rules and test and reformulate hypotheses. In the TRIG lesson, visual representations of trigonometric functions allowed for immediate feedback, allowing learners to concentrate more on mathematical relationships rather than on the mechanics of construction. The analysis also showed that pre-service teachers used the spreadsheet environment and the student worksheet to engage their students in different learning-related activities. In the TBV lesson for example, students viewed a presentation, collected data (on coordinates of an object) and made predictions of the image location when the object was rotated by a vector. With the QPF lesson, students collaborated to explore the properties of quadratic functions and presented their work to their peers in teams for peer assessment.

Table 4. Mean score responses for TPACK in lesson plans ( $N = 6$ ).

	TBV		DBTGP		TRIG		QVF		QPF		GLE		All lessons	
	Cds	M (SD)	Cds	M (SD)	Cds	M (SD)	Cds	M (SD)	Cds	M (SD)	Cds	M (SD)	TCds	M (SD)
TK <sub>ss</sub>	7	2.40 (.414)	8	2.55 (.512)	10	2.50 (.434)	9	2.45 (.547)	9	2.47 (.444)	8	2.50 (.535)	51	2.48 (.051)
CK <sub>maths</sub>	11	2.48 (.404)	11	2.50 (.453)	12	2.50 (.511)	11	2.45 (.499)	10	2.60 (.567)	12	2.67 (.492)	67	2.53 (.084)
PK <sub>ABL</sub>	8	2.46 (.557)	9	2.45 (.349)	9	2.49 (.475)	9	2.60 (.541)	10	2.55 (.486)	9	2.80 (.447)	54	2.56 (.131)
PCK <sub>ABL</sub>	6	2.44 (.561)	7	2.48 (.500)	7	2.43 (.544)	9	2.40 (.343)	7	2.44 (.576)	7	2.57 (.535)	43	2.46 (.060)
TPK <sub>ABL</sub>	5	2.46 (.449)	5	2.40 (.511)	5	2.45 (.436)	6	2.39 (.321)	6	2.42 (.438)	5	2.40 (.548)	32	2.42 (.028)
TCK <sub>ss</sub>	5	2.38 (.467)	5	2.56 (.487)	5	2.44 (.422)	6	2.41 (.436)	7	2.41 (.551)	4	2.50 (.577)	32	2.45 (.068)
TPCK <sub>maths</sub>	6	2.40 (.500)	6	2.42 (.442)	6	2.44 (.345)	7	2.46 (.444)	7	2.48 (.431)	6	2.50 (.548)	38	2.45 (.037)

Cds = number of codes, TCds = total number of codes.

The pre-service teachers who taught their peers found some difficulty using the spreadsheet to develop mathematical concepts well to support their students' understanding. For instance, it was a struggle for the teacher (lesson QPF, Figure 2) to demonstrate that the basic second-degree curve  $y = ax^2 + bx + k$  gives a thinner parabola if  $|a|$  is increasing and a flatter parabola if  $|a|$  is decreasing. It was also difficult to illustrate that as the absolute value of  $m$  increases the graph of  $y = mx + k$  become steeper and vice versa in the lesson on GLE (Figure 2). 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 (pre-service teachers displayed graph after graph on the same spreadsheet when the coefficients were altered). Such similar difficulties were encountered in the other lessons as well. The corresponding subsequent lessons for secondary school students were less of a struggle. The pre-service teachers were able to present the concepts better by demonstrating the different values of the coefficients with their respective graphs on the same spreadsheet as shown below for lessons QPF and GLE.

This suggests that the results and insights learned from the teaching try-outs (peer teaching) served as necessary inputs for the classroom pre-service teachers in revising and implementing their designs particularly in spreadsheet-related constructs:  $TK_{ss}$ ,  $TPK_{ABL}$ ,  $TCK_{ABL}$  and  $TPCK_{maths}$ . As a result, their final designs reflected relatively high scores for  $TK_{ss}$ ,  $TPK_{ABL}$ ,  $TCK_{ABL}$  and  $TPCK_{maths}$  (see Table 5). Table 5 shows that differences in these constructs  $TK_{ss}$ ,  $TPK_{ABL}$ ,  $TCK_{ABL}$  and  $TPCK_{maths}$  for the peer pre-service teachers and classroom pre-service teachers were significant ( $p = 0.021, 0.019, 0.006$  and  $0.005$ ) with large effect sizes.

### Pre-service teachers' self-reported TPACK development

Table 6 gives a summary of the results of the respondents' pre- and post-test means for all seven TPACK subscales in a one-tailed Wilcoxon test.

The results showed significant changes in all components of TPACK with largest areas of change occurring in subscales related to technology integration knowledge and skills:  $TPK_{ABL}$  (gain = 2.62),  $TCK_{ss}$  (gain = 2.61),  $TK_{ss}$  (gain = 2.40) and  $TPCK_{maths}$  (gain = 2.38). The next two subscales with the highest change were

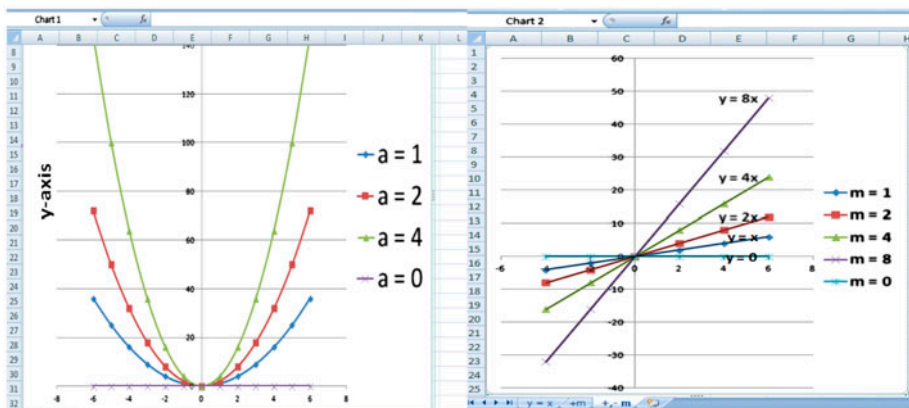


Figure 2. Graph of  $y = ax^2 + bx + k$  and graph of  $y = mx + k$ .

Table 5. Wilcoxon test results for peer teaching and classroom teaching mean score responses for TPACK subscales ( $N = 6$ ).

TK <sub>ss</sub>	TBV		DBTGP		TRIG		QVF		QPF		GLE		Overall		Effect size
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Sig. ( <i>p</i> )	
CT	2.33 (0.712)	2.45 (0.654)	2.33 (0.489)	2.29 (0.543)	2.33 (0.312)	2.40 (0.442)	2.35 (0.057)	0.021**	2.2						
	2.23 (0.357)	2.33 (0.567)	2.33 (0.457)	2.30 (0.359)	2.22 (0.352)	2.24 (0.349)	2.27 (0.052)								
CK <sub>maths</sub>	2.57 (0.389)	2.65 (0.444)	2.57 (0.383)	2.57 (0.374)	2.62 (0.546)	2.64 (0.534)	2.61 (0.039)	0.970	0.03						
	2.57 (0.459)	2.64 (0.453)	2.57 (0.309)	2.57 (0.446)	2.62 (0.443)	2.63 (0.453)	2.60 (0.034)								
PK <sub>ABL</sub>	2.47 (0.462)	2.62 (0.435)	2.53 (0.432)	2.54 (0.415)	2.60 (0.472)	2.62 (0.531)	2.56 (0.059)	0.938	0.065						
	2.50 (0.301)	2.62 (0.421)	2.52 (0.377)	2.53 (0.501)	2.59 (0.401)	2.61 (0.654)	2.56 (0.050)								
PCK <sub>ABL</sub>	2.36 (0.430)	2.51 (0.440)	2.38 (0.444)	2.40 (0.523)	2.41 (0.569)	2.46 (0.476)	2.42 (0.055)	0.940	-0.05						
	2.36 (0.521)	2.52 (0.421)	2.39 (0.435)	2.40 (0.528)	2.42 (0.529)	2.45 (0.555)	2.42 (0.057)								
TPK <sub>ABL</sub>	2.25 (0.628)	2.42 (0.528)	2.25 (0.458)	2.21 (0.436)	2.33 (0.514)	2.38 (0.625)	2.30 (0.082)	0.019**	1.7						
	2.19 (0.309)	2.15 (0.409)	2.22 (0.432)	2.18 (0.459)	2.11 (0.613)	2.27 (0.556)	2.19 (0.055)								
TCK <sub>ss</sub>	2.25 (0.652)	2.44 (0.772)	2.26 (0.656)	2.22 (0.552)	2.38 (0.543)	2.33 (0.452)	2.31 (0.086)	0.006*	2.5						
	2.19 (0.313)	2.11 (0.613)	2.21 (0.546)	2.18 (0.624)	2.19 (0.524)	2.09 (0.513)	2.16 (0.049)								
TPCK <sub>maths</sub>	2.25 (0.852)	2.42 (0.652)	2.25 (0.657)	2.20 (0.605)	2.30 (0.652)	2.38 (0.654)	2.30 (0.085)	0.005*	2.08						
	2.01 (0.708)	2.12 (0.568)	2.15 (0.507)	2.14 (0.567)	2.25 (0.654)	2.11 (0.564)	2.13 (0.076)								

\*  $p < .01$ ; \*\*  $p < .05$ , CT = classroom teaching, PT = peer teaching.

Table 6. Wilcoxon test results for pre- and post-test mean score responses for TPACK subscales ( $N = 12$ ).

TPACK subscales	Mean ( <i>SD</i> )	<i>Z</i>	<i>P</i>	Effect size
TK <sub>ss</sub>				
Pre-test	2.93 (0.712)	-3.06	0.002*	2.40
Post-test	4.27 (0.357)			
CK <sub>maths</sub>				
Pre-test	4.14 (0.389)	-2.21	0.027**	0.70
Post-test	4.44 (0.459)			
PK <sub>ABL</sub>				
Pre-test	4.05 (0.462)	-2.55	0.011**	1.15
Post-test	4.50 (0.301)			
PCK <sub>ABL</sub>				
Pre-test	4.00 (0.430)	-2.45	0.014**	1.05
Post-test	4.50 (0.521)			
TPK <sub>ABL</sub>				
Pre-test	3.18 (0.628)	-2.94	0.003*	2.62
Post-test	4.48 (0.309)			
TCK <sub>ss</sub>				
Pre-test	3.17 (0.652)	-3.02	0.003*	2.61
Post-test	4.50 (0.313)			
TPCK <sub>maths</sub>				
Pre-test	2.63 (1.052)	-3.06	0.002*	2.38
Post-test	4.47 (0.308)			

\*  $p < .01$ ; \*\*  $p < .05$ .

PK<sub>ABL</sub> (gain = 1.15) and PCK<sub>ABL</sub> (gain = 1.05), and both differences were statistically significant at 0.05 level. The pre-service teachers' responses in CK<sub>maths</sub> (gain = 0.70) reported a fairly low gain, but was also significant at 0.05 level. A possible reason for the relatively low gains in the pre-service teachers' PK<sub>ABL</sub>, PCK<sub>ABL</sub> and CK<sub>maths</sub> compared with TK<sub>ss</sub>, TCK<sub>ss</sub>, TPK<sub>ABL</sub> and TPCK<sub>maths</sub> was the difficulty in assessing their own abilities needed to design and enact ABL lessons. Apparently, the pre-service teachers initially rated themselves highly on the PK<sub>ABL</sub> and PCK<sub>ABL</sub> scales (because of their perceived knowledge and skills on pedagogical issues and their application in teaching mathematics content), while this was not the case with the technology-related subscales which they perceived as new; they basically realised that PK<sub>ABL</sub> and PCK<sub>ABL</sub> were also new. Furthermore, the pre-service teachers initially rated their CK<sub>maths</sub> as high, but might have expanded their knowledge about some mathematical concepts not because it was new, but because they realised they did not yet completely understand these concepts. These observations were reiterated in the interview data. For instance, three pre-service teachers indicated:

... and my understanding in quadratics was broadened as we explored the teaching activities we had designed in our lesson. (CK<sub>maths</sub>) (T52)

I have learnt a great deal of activity-based pedagogical approach of teaching mathematics and I hope to use it extensively in my future lessons. (PK<sub>ABL</sub>) (T41)

By observing how changes in the variables had immediate feedback on the graph, I got first-hand information on the role played by each part of the equation. (PCK<sub>ABL</sub>) (T44)



In the interview, pre-service teachers reported on the usefulness, experiences and several challenges in designing and enacting spreadsheet-supported ABL lessons. The pre-service teachers indicated several reasons why spreadsheet-supported ABL served a useful pedagogical approach. They included: *Promotes collaborative learning* (12), *Promotes active learning* (12), *Allow teachers more time to reflect on the learning that is taking place* (8). Others were: *Helped student evaluate their own work and that of others* (10), *Helped students share their evaluations* (9) and *Helped students to be responsible for their own learning* (9).

According to them, spreadsheet demonstrations of the mathematical concepts generated active interactions among their students and in most cases supported their students to develop their own knowledge in higher concepts. Two pre-service teachers explained in an interview:

Indeed I have been taught trigonometric functions before and I taught a similar lesson during my off-campus teaching practice; but the use of the spreadsheet in this lesson made it more practical promoting students' involvement. (T41)

to me it was far better than the normal teaching in the senior high school classroom because the lesson was more practical and the concepts were easier to develop. (T11)

While pre-service teachers in the study understood the importance of using the spreadsheet-supported ABL approach, they indicated that implementing spreadsheet-supported ABL could be time-consuming. A number of them found difficulty in completing lessons within the stipulated time.

Another challenge the pre-service teachers faced had to do with the design process itself. They reported the following problematic and difficult areas they had experienced during the design of their lesson: designing authentic learning activities for their chosen topics as well as selecting and matching appropriate integrating spreadsheet tools and relevant resources in designing mathematics learning activities. The pre-service teachers also reported that it was time-consuming to develop activity-based lessons supported by spreadsheets. For example in team two, a member indicated:

In designing the learning activities for our students' worksheet, we went through a lot of thoughts. We had difficulty designing a task that will promote active learning and at the same time help student consolidate their learning. (T21)

The second member of the same team also indicated:

We had to strike a balance between making the activities suitable for collaborative learning and at the same time meeting the learning objectives. In addition, the activities had to be innovative and creative, so it took us a long time in accomplishing this task. (T22)

The following responses confirmed pre-service teachers' challenges in selecting appropriate integrating spreadsheet tools and relevant resources in their designing activities:

With the options of spreadsheet capabilities, it was difficult for us to select the appropriate applications in designing the teaching activities in our lesson. (T11)

It was difficult to think of appropriate spreadsheet applications that tied in with the topic (Trigonometric functions) we taught. (T32)

Deciding on what concepts that needed the incorporation of spreadsheet application was a struggle in our case. (T51)

In spite of this, pre-service teachers were of the view that implementation of the spreadsheet-supported ABL reflected good practices of learner-centredness in their classrooms.

## Discussion

In this study, pre-service mathematics teachers collaboratively designed and used spreadsheet teaching materials to enact an ABL within a mathematics classroom context.

The pre-service teachers were challenged to select mathematics topics suitable for teaching with spreadsheets, and to make use of the affordances of the technology to design learning activities that foster higher order thinking in mathematics. The result of the study showed that the combination of a specific pedagogy (ABL) and a specific technology (spreadsheets) encouraged the pre-service teachers to apply their knowledge and skills in designing and enacting ABL lessons by employing a mix of direct instruction and hands-on activity (Hmelo-Silver et al., 2008; Mayer, 2004) via worksheets to guide students through activities with spreadsheets to enhance their learning. Learners had greater opportunity to verify results and consider general rules, make links between spreadsheet formula, algebraic functions and graphs, analyse and explore number patterns and graphs within a shorter time and allow for many numerical calculations simultaneously. Thus, the spreadsheet environment appeared useful to engage pre-service teachers in the design of learning activities to support mathematics learning of students, such as: discussing presentations, collecting data (e.g. on the coordinates of an object), working in teams, making predictions. This variety of learning activities offered the pre-service teachers the opportunity to orchestrate student learning in various ways (cf. Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010). This is the kind of pedagogical reasoning (cf. Webb & Cox, 2004) that pre-service teachers need to undertake in their planning and teaching of ICT-enhanced lessons.

The study also showed that the ABL approach prompted clearly defined roles for both students and pre-service teachers. Students worked collaboratively in groups, had the opportunity to evaluate their own work and that of others sharing their evaluations. The role of the pre-service teachers, on the other hand, depicted them more as facilitators than dispensers of knowledge; managing the context and setting and assisting students in developing mathematical concepts through activities.

Clearly, the study showed that pre-service teachers demonstrated knowledge and skills in designing and enacting activity-based lessons supported with spreadsheets. This was evident not only in their lesson plan products and observed instruction but their self-reported data as well. Significant gains in all the TPACK components of the pre-service teachers' self-reported data attest to this.

For example, the pre-service teachers perceived that their knowledge and skills had developed more in areas in which the 'T' is involved compared with their  $PK_{ABL}$ ,  $CK_{maths}$  and  $PCK_{ABL}$ . A possible reason for the relatively low gains in the pre-service teachers'  $PK_{ABL}$  and  $PCK_{ABL}$  was the difficulty in assessing their own abilities in an unknown knowledge/skill domain. The pre-service teachers initially rated themselves high on  $PK_{ABL}$  and  $PCK_{ABL}$ , but after having experienced the potential of ABL lessons they might have realised that they never had considered other pedagogical approaches than the ones they were used to. The findings also illuminate that the pre-service teachers initially rated their  $CK_{maths}$  as high, but expanded their own

understanding of mathematical concepts as they explored the spreadsheet-supported ABL lessons' pedagogical approach. Thus, findings of the study suggest that as novice pre-service teachers, the new experience with spreadsheets and ABL impacted on their knowledge and skills regarding all the TPACK constructs.

In spite of the advantages of the pedagogical approach, the pre-service teachers reported some difficulties in applying their knowledge and skill designing and enacting activity-based lessons supported with spreadsheets. The 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. This is consistent with findings by Niess et al. (2010–11) and Niess (2011) that mathematics teachers are still confronted with challenges and questions of how and when to incorporate technologies for teaching and learning various subject matter topics. It is apparent that the range of spreadsheet capabilities is limited and that for many mathematics concepts, spreadsheet applications are not relevant. As a result, most teachers might have experienced difficulty in making spreadsheet application choices and in matching learning activities which they employed in their instructional plans. The context-sensitive factor in which pre-service teachers have been deep-rooted in a teacher-centred learning approach could also have influenced their thinking and practices.

The concern of time was reiterated by the pre-service teachers, indicating that conducting a spreadsheet-supported ABL lesson involved a lot of time and required a kind of subject-specific training with technology. These drawbacks notwithstanding, the spreadsheet-supported ABL imparted positively on pre-service teachers' experiences and lesson enactment outcomes.

## **Conclusion**

Findings of the study showed that ABL pedagogy can play a vital role in enhancing pre-service teachers' skills and their experience in integrating technology in their future classes. Furthermore, the study supports arguments that the spreadsheet-supported ABL approach fostered learner-centred classroom practices and has the potential to improve mathematics achievement in senior high schools. The results also indicated that in spite of design challenges, exposing pre-service teachers to activity-based learning supported with spreadsheets is a good way to help pre-service teachers develop deeper connections between their subject matter, instructional strategy and spreadsheet applications fostering the knowledge base of TPACK. Such a conclusion poses a question on TPACK's applicability in different contexts and technologies to assess pre-service teachers on a more generic level. Therefore, the study contends that for pre-service teachers to understand and develop knowledge/skill related to TPACK in a valid and reliable way, it is important for them to focus on a specific content as well as a specific pedagogical approach in which a specific technology can be integrated. This aligns to Shulman's (1986) idea of a teacher's PCK characterised as 'knowledge of the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations ... including an understanding of what makes the learning of specific concepts easy or difficult' (p. 9). A possible next step of this study will be to scale up the professional development approach to the institutional level to foster adoption of the innovation by many pre-service teachers. Accordingly, a mathematics-specific

instructional technology course is recommended which incorporates findings of this study, to develop pre-service teachers' knowledge and skill in teaching mathematics with technology using the ABL pedagogical approach.

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### References

- Agyei, D. D. (2012). *Preparation of pre-service teachers in Ghana to integrate information and communication technology in teaching mathematics*. Enschede: University of Twente.
- Agyei, D. D., & Voogt, J. (2011a). ICT use in the teaching of mathematics: Implications for professional development of pre-service teachers in Ghana. *Education and Information Technologies*, 16, 423–439.
- Agyei, D. D., & Voogt, J. (2011b). Exploring the potential of the Will Skill Tool model in Ghana: Predicting prospective and practicing teachers' use of technology. *Computers & Education*, 56, 91–100.
- Beauchamp, G., & Parkinson, J. (2008). Pupils' attitudes towards school science as they transfer from an ICT-rich primary school to a secondary school with fewer ICT resources: Does ICT matter? *Education Information Technology*, 13, 103–118.
- Bottino, R. M., & Robotti, E. (2007). Transforming classroom teaching and learning through technology: Analysis of a case study. *Educational Technology & Society*, 10, 174–186.
- Churchill, D. (2004). Effective use of technology for construction of learners' mental models. In A. Khoo, M. A. Heng, L. Lim, & R. P. Ang (Eds.), *Innovation and diversity in education* (pp. 333–349). Singapore: McGraw-Hill (Asia).
- Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. London: Routledge.
- Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Whole-class teaching behavior in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, 75, 213–234.
- Harris, J., Grandgenett, N., & Hofer, M. (2010). Testing a TPACK-based technology integration assessment rubric. In D. Gibson & B. Dodge (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010* (pp. 3833–3840). Chesapeake, VA: AACE.
- Harris, J., Mishra, P., & Koehler, A. M. (2009). Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed. *Research on Technology in Education*, 41, 393–416.

- Hartsell, T., Herron, S., Fang, H., & Rathod, A. (2009). Effectiveness of professional development in teaching mathematics and technology applications. *Journal of Educational Technology Development and Exchange*, 2, 53–56.
- Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2008). Scaffolding and achievement in problem-based inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99–107.
- Hofer, M., Grandgenett, N., Harris, J., & Swan, K. (2011). Testing a TPACK-based technology integration observation instrument. In M. Koehler & P. Mishra (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2011* (pp. 4352–4359). Chesapeake, VA: AACE.
- Keong, C., Horani, S., & Daniel, J. (2005). A study on the use of ICT in mathematics teaching. *Malaysian Online Journal of Instructional Technology*, 2(3), 43–51.
- Koehler, M. J., & Mishra, P. (2008). Introducing technological pedagogical content knowledge. In AACTE Committee on Innovation and Technology (Eds.), *Handbook of technological pedagogical content knowledge for teaching and teacher educators* (pp. 3–29). New York, NY: Routledge.
- Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education*, 49, 740–762.
- Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist*, 59, 14–19.
- Miles, M. B., & Huberman, A. M. (1994). *An expanded source book: Qualitative data analysis* (2nd ed.). London: Sage Publications.
- Ministry of Education. (2000). *Teaching syllabus for mathematics*. Accra, Ghana: Author.
- Ministry of Education, Science and Sports. (2007). *Teaching syllabus for mathematics*. Accra, Ghana: Author.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record*, 108, 1017–1054.
- Mullis, I. V. S., Martin, M. O., & Foy, P. (2008). *International mathematics report: Findings from IEA's Trends in International Mathematics and Science Study at the fourth and eighth grades*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.
- National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.
- Niess, M. L. (2008). Knowledge needed for teaching with technologies – Call it TPACK. *AMTE Connections*, Spring, 9–10.
- Niess, M. L. (2011). Investigating TPACK: Knowledge growth in teaching with technology. *Journal of Educational Computing Research*, 44, 299–317.
- Niess, M. L., Sadri, P., & Lee, K. (2007, April). *Dynamic spreadsheets as learning technology tools: Developing teachers' technology pedagogical content knowledge (TPCK)*. Paper presented at the meeting of the American Educational Research Association Annual Conference, Chicago, IL.
- Niess, M. L., van Zee, E., & Gillow-Wilese, H. (2010–11). Knowledge growth in teaching mathematics/science with spreadsheets: Moving PCK to TPACK through online professional development. *Journal of Digital Learning in Teacher Education*, 27(2), 42–52.
- Ottevanger, W., van den Akker, J. J. H., & de Feiter, L. (2007). *Developing science, mathematics and ICT education in Sub-Saharan Africa: Patterns and promising practices*. World Bank Working Paper no. 101, Africa Human Development Series. Washington, DC: The World Bank.
- Schmidt, D. A., Baran, E., Thompson, A. S., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological Pedagogical Content Knowledge (TPACK): The development and validation of an assessment instrument for pre-service teachers. *Journal of Research on Technology in Education*, 42, 123–149.
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15, 4–14.

- So, H., & Kim, B. (2009). Learning about problem based learning: Student teachers integrating technology, pedagogy and content knowledge. *Australasian Journal of Educational Technology*, 25, 101–116.
- Webb, M., & Cox, M. (2004). A review of pedagogy rated to information and communications technology. *Technology, Pedagogy and Education*, 13, 235–286.