Pre-service Mathematics Teachers' Learning and Teaching of Activity-Based Lessons Supported with Spreadsheets

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Abstract: Mathematics education research has shown that too few students have adequate mathematics comprehension or problem-solving skills. To make up for this lapse in student outcomes, mathematics teachers should be among the most enthusiastic in seeking to maximize technologies' potential to develop student understanding, stimulate student interest, and increase student mathematics proficiency. In this study, pre-service mathematics teachers worked in teams to develop their knowledge and skills in designing activity-based lessons supported by spreadsheets. The pre-service teachers developed and demonstrated their knowledge and skill adequately during the design and enactment of their lessons. The results also showed that, the activity-based lessons supported by spreadsheets served a useful pedagogical approach, impacted on student learning outcomes and has the potential of improving teaching and learning mathematics in secondary education.

Introduction

In Ghana, mathematics is a required subject at all levels in pre-university education. Due to its 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). Among the reasons for these low achievements, the method of teaching mathematics is considered one prominent factor. 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), involves whole class teaching, lots of notes being copied, and hardly any hands-on activities, where teachers rush to cover all the topics mechanically in order to finish on time for examinations rather than striving for indepth student learning (Ottevanger et al, 2007). Such teacher-centred instructional methods have been criticized for failing to prepare students to attain high achievement levels in mathematics (Hartzell, 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 internalize new knowledge from their experiences (MOE, 2000). For example, the new curriculum in Mathematics at the Senior High School (SHS) places emphasis on skill acquisition, creativity and the arts of enquiry and problem solving (MOESS 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. 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 it in lesson plans and lesson enactment. Professional development is therefore critical towards helping pre-service teachers to develop the proper skill set and required knowledge before such instructional change can occur. In this study, a professional development arrangement in which pre-service teachers collaboratively design and use technology –supported lesson teaching materials is carried out for pre-service mathematics teachers. In the study, technology is presented as a tool for enacting a guided activity-based pedagogical approach (referred to as Activity-Based Learning) of teaching mathematical concepts to develop pre-service teachers’ knowledge and skills in teaching with technology, in particular spreadsheets, and measure the impact of the lesson enactment on students’ learning outcomes.

The Professional Development Arrangement

In this study TPACK has been used as a conceptual framework to examine the knowledge and skills pre-service math 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 it was readily available in SHSs and in teacher Education Colleges (Agyei & Voogt, 2011a, b), user friendly and had the potential of supporting students’ higher-order thinking in mathematics (Agyei & Voogt, submitted; Niess, Sadri, & Lee, 2007). Content knowledge (CK_{maths}) was mathematics which was the pre-service teachers teaching subject area.

Figure1: Framework of TPACK for this study

In the study, pre-service teachers' knowledge and skills which are needed to teach spreadsheet supported ABL lessons in mathematics was operationalised as their TPACK, and consists of the following specific knowledge and skills:

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

The professional development arrangement (PD) was based on 'learning technology by design' (Mishra & Koehler, 2006) and has been described extensively in Agyei and Voogt (submitted). In the PD Pre-service teachers collaboratively designed and enacted spreadsheet-support ABL lessons. The PD consisted of three stages: An introductory workshop for Design Teams (DTs), design of lessons in DTs and implementation of lessons by DT members. The workshop lasted for two weeks and prepared the pre-service teachers by giving them the theoretical foundation/concepts as well as practical skills. Exemplary materials consisting of two models of activity-based lessons supported with spreadsheet that were prepared by the researcher and appraised by an expert with ample experience in the use of technology in teaching mathematics were a necessary component of the PD arrangement. Based on their experiences, the teachers worked in teams of two to develop and model their own lessons (in suitable mathematics topics from the SHS curriculum) after the exemplary materials during the design stage (six weeks). In the implementation stage (five weeks) each lesson was enacted by teaching to their peer pre-service teachers and in three secondary high schools. Consequently six activity-based lessons supported with spreadsheet were developed and enacted two times each at different stages of implementation. 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 a LCD projector available to the teacher. The researcher acted mainly as a facilitator, coach and observer in different stages of the study.

Instruments

In Table 1 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 students for the activity-based lessons supported with spreadsheet is presented.

Table 1: 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	Student Test
Knowledge and skill demonstration	✓ (post)	✓ (post)			✓	
Perceived knowledge and skill development			✓ (pre-post)	✓ (post)		
Learning						✓

outcomes						(pre-post)
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Logbook was used by researcher during design and implementation of the lessons

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 spreadsheet (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 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_{ABL})(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_{ABL})(DBTGP). Analysis of the document also showed that specific roles were identified for the teachers as well as the students. Most lessons showed various tasks to be done by students (ie observing, recording, exploring etc) while 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 ($TPCK_{maths}$)(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 ($TPCK_{maths}$)(GLE). Prepare students for the following activities (Activities: 1.0 – 3.0) by organizing them in small groups.... (PK_{ABL})(TBV). Analysis the lesson plan documents, the results showed fairly high TPACK evidence; with the highest mean scores in PK_{ABL} (2.56, 0.131) and CK_{maths} (2.53, 0.084) and least mean scores in TPK_{ABL} (2.42, 0.028).

Lesson Enactment

During lesson enactment, the teachers used their lesson plans to guide class instruction using “interactive demonstration” in a spreadsheet environment. All teachers introduced the fundamental concepts of their lessons by using spreadsheet and gradually engaged their students to develop higher concepts as lessons progressed. For instance in the QVF lesson 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 explore 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 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 view 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. The 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 2a) 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 2b). 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 (teachers displayed graph after graph on the same spreadsheet when the co-efficients 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 teachers were able to present the concepts better by demonstrating the different values of the co-efficients with their respective graphs on the same spreadsheet as shown below for lessons QPF and GLE.

Figure 2: a. Graph of: $y = ax^2 + bx + k$

b. Graph of: $y = mx + k$

This suggests that the results and insights learned from the teaching try-outs (peer teaching) served as necessary inputs for the classroom 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 $TPCK_{maths}$ as were assessed in their observed lessons. Differences in the constructs TK_{ss} , TPK_{ABL} , TCK_{ABL} and $TPCK_{maths}$ for the peer teachers and classroom teachers were significant ($p=0.021$, 0.019 , 0.006 and 0.005) with large effect sizes ($d=2.2$, 1.7 , 2.5 and 2.08) respectively.

Pre-service Teachers' Self-reported TPACK Development

Table 2 gives a summary of the results of the respondents' pre- and post-test means for all seven TPACK sub-scales 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 $TPCK_{maths}$ (2.38). The next two sub-scales with the highest change were PK_{ABL} (gain = 1.15) and PCK_{ABL} (gain = 1.05), and both differences were statistically significant at 0.05 level. The teachers' responses in CK_{maths} (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 teachers' PK_{ABL} , PCK_{ABL} and CK_{maths} compared to TK_{ss} , TCK_{ss} , TPK_{ABL} and $TPCK_{maths}$ was the difficulty in assessing their own abilities needed to design and enact ABL lessons. Apparently, the pre-service teachers initially rated themselves high on the PK_{ABL} and PCK_{ABL} scales (because of their perceived knowledge and skills on pedagogical issues and its application in teaching mathematics content), while this was not the case with the technology-related subscales which they perceived as new; they basically realized that PK_{ABL} and PCK_{ABL} were also new.

Table 2: Wilcoxon test results for pre- and post-test mean score responses for TPACK Subscales (N=12)

TPACK Sub-scales	Mean (SD)	Z	P	Effect size
TK_{ss}				
Pre-test	2.93 (0.712)	- 3.06	0.002*	2.40
Post-test	4.27 (0.357)			
CK_{maths}				
Pre-test	4.14 (0.389)	- 2.21	0.027**	0.70
Post-test	4.44 (0.459)			
PK_{ABL}				
Pre-test	4.05 (0.462)	-2.55	0.011**	1.15
Post-test	4.50 (0.301)			
PCK_{ABL}				
Pre-test	4.00 (0.430)	-2.45	0.014**	1.05
Post-test	4.50 (0.521)			
TPK_{ABL}				
Pre-test	3.18 (0.628)	-2.94	0.003*	2.62
Post- test	4.48 (0.309)			

TCK _{ss}				
Pre-test	3.17 (0.652)	-3.02	0.003*	2.61
Post-test	4.50 (0.313)			
TPCK _{maths}				
Pre-test	2.63(1.052)	-3.06	0.002*	2.38
Post-test	4.47(0.308)			

* = $p < .01$, ** = $p < .05$

Furthermore, the teachers initially rated their CK_{maths} high, but might have expanded their knowledge about some mathematical concepts not because it was new, but because they realized they did not yet completely understand these concepts. In the interview teachers reported on the usefulness, impact and several challenges in designing and enacting spreadsheet-supported ABL lessons. The teachers indicated that spreadsheet-supported ABL served a useful pedagogical approach for a number of reasons (Table 3).

Table 3: Interview responses for designing and teaching ABL (N=12)

Question	Response	f
What are your reflections on the spreadsheet-supported ABL lessons?	Promotes collaborative learning	12
	Promotes active learning	12
	Allow teachers more time to reflect on the learning that is taking place	8
How, do you think the approach helped your students to learn?	Helped student evaluate their own work and that of others	10
	Helped students share their evaluations	9
	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 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 SHS 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. 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 following responses confirmed teachers' challenges in selecting appropriate integrating spreadsheet tools and relevant resources in their designing activities: *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.

Student Cognitive Outcomes

A paired sample t-test showed significant ($p < 0.0001$) difference in the learning outcomes of the pre- and post test scores with large effect sizes (ranging from 1.19 - 4.47) for all six lessons. For two lessons (QVF and TBV) it was possible to compare the mean gains test scores for students following the spreadsheet-supported ABL (SSL) lesson and those of the traditional approach (TM). Table 4 provides an overview of the results.

Table 4: Mean gain test score between spreadsheet-supported ABL (SSL) and traditional approach(TM)

Lessons	SSL		Traditional(TM)		Effect Size	Sig P
	Mean Gain	SD	Mean Gain	SD		
QVF (SSL=36, TM=34)	4.28	1.523	3.15	1.258	0.81	0.001*
TBV (SSL=35, TM=38)	1.86	1.258	1.08	1.399	0.59	0.015*
Overall (SSL=71, TM=72)	3.08	1.849	2.06	1.686	0.58	0.001*

* $P < 0.05$

Table 4 indicated high mean gains for the lesson on QVF. A possible reason which explains the relatively high mean values was that, the lesson was taught the second time in the classes involved. Differences in both lessons (QVF = 0.001, TBV= 0.015) proved to be significant with effect sizes (QVF = 0.81, TBV=0.59). The overall difference between the means (SSL=3.08, TM= 2.06) for both lessons was significant ($p=0.001$) with effect size 0.58 indicating that the spreadsheet-supported ABL lessons impacted more positively on the students' outcomes.

Discussion

The lesson documents and lesson enactment showed that the pre-service teachers employed a mix of direct instruction and hands-on activity to guide students through activities in which the students explored, conjectured, verified, generalized, and applied results to other settings and realistic mathematical problems consistent with other studies (Mayer, 2004; Hmelo-Silver, Duncan, & Chinn, 2008). The teachers used spreadsheet extensively to give 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, to help their students explore mathematics concepts and perform authentic tasks. This confirms similar studies (Özgün-Koca, Meagher & Edwards 2010), that pre-service teachers understanding of technology shift from viewing technology as a tool for reinforcement into viewing technology as a tool for developing student understanding of mathematical concepts.

The study also showed that the ABL approach prompted clearly defined roles for both students and 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 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. The teachers' demonstrated knowledge and skills in designing and enacting activity-based lessons supported with spreadsheet in their lesson plan products and observed instruction. This was confirmed by their perceived development in the knowledge and skill needed to design and enact spreadsheet-supported ABL lessons as were observed by significant gains in all the TPACK components of the teachers' self-reported data.

In particular, the teachers perceived that their knowledge and skills had developed more in areas which the 'T' is involved compared to their PK_{ABL} , CK_{maths} and PCK_{ABL} . A possible reason for the relatively low gains in the teachers' PK_{ABL} and PCK_{ABL} was the difficulty in assessing their own abilities in an unknown knowledge/skill domain. The teachers' initially rated themselves high on PK_{ABL} and PCK_{ABL} , but after having experienced the potential of ABL lessons they might have realized that they never had considered other pedagogical approaches than the ones they were used to. The findings also illuminate that, the teachers initially rated their CK_{maths} 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 teachers, the new experience with spreadsheet and ABL impacted on their knowledge and skills regarding all the TPACK constructs.

In spite of the advantages of the pedagogical approach, the teachers reported some difficulties in applying their knowledge and skill designing and enacting activity-based lessons supported with spreadsheet. The areas they identified to be particularly challenging and difficult included: selecting and integrating appropriate spreadsheet tools and relevant spreadsheet application in designing authentic learning activities for selected 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 teacher-centered learning approach could have influenced their thinking and practices. The concern of time was reiterated by the teachers; indicating that conducting a spreadsheet-supported ABL lessons involved a lot of time and required a kind of subject-specific training with technology. These drawbacks notwithstanding, the spreadsheet-supported ABL impacted their secondary students learning outcomes. The mean gains in the spreadsheet-supported ABL approach compared to the traditionally taught lessons showed significance difference with a medium to high effect size which confirms previous studies (cf. Keong, Horani & Daniel, 2005) that technology use improves the way mathematics is taught and enhances students' understanding of basic concepts and have positive effect on student achievement in mathematics (cf. Bottino & Robotti, 2007; Beauchamp & Parkinson, 2008).

Findings of the study showed that ABL pedagogy can play a vital role in enhancing pre-service teachers' skill and their experience to integrate technology in their future classes. Furthermore the study supports arguments that spreadsheet-supported ABL approach fostered learner-centered classroom practices and has potential of

improving mathematics achievement in senior high schools. The results also indicated that in spite of design challenges, exposing teachers to activity-based learning supported with spreadsheet is a good way to help pre-service teachers develop deeper connections between their subject matter, instructional strategy and spreadsheet application fostering knowledge -base of TPACK. Such a conclusion poses a question on TPACK's applicability in different context and technologies to assess teachers on a more generic level. Therefore, the study contends that for 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 specific pedagogical approach in which a specific technology can be integrated. This aligns to Shulman (1986) idea of a teachers' PCK characterized 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).

References

- 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(4),423-439.
- Agyei, D. D., & Voogt, J. M. (2011). 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(4), 174-186.
- 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(1), 53-6.
- 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.
- 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.
- Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist* 59 (1): 14–19.
- Ministry of Education, Science and Sports. (MOESS)(2007). *Teaching Syllabus for Mathematics*, Ministry of Education, Accra, Ghana.
- Ministry of Education, (2000). *Teaching Syllabus for Mathematics*, Ministry of Education, Accra, Ghana.
- Mishra, P. & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record*, 108(6), 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.
- 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.
- Ottevanger, W., van den Akker, J.J.H. & de Feiter, L., (2007). *Developing Science, Mathematics and ICT education in Sub-Saharan Africa (SMICT): Patterns and promising practices*, World Bank Working Paper (101), pp. 1-84.
- Özgün-Koca, A., Meagher, M., & Edwards, M. T. (2009/2010). Preservice Teachers' Emerging TPACK in a Technology-Rich Methods Class. *The Mathematics Educator*, 19(2), 10–20.
- 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(1), 101-116.