Using technology pedagogical content knowledge development to enhance learning outcomes

Article *in* Education and Information Technologies · March 2014

DOI: 10.1007/s10639-012-9204-1

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Educ Inf Technol (2014) 19:155–171
DOI 10.1007/s10639-012-9204-1

Using technology pedagogical content knowledge development to enhance learning outcomes

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Published online: 30 May 2012

Abstract This paper describes an intervention in which pre-service teachers developed their TPACK through multiple data sources. Teachers' self-reports of their TPACK knowledge were triangulated with performance-based assessment of their instructional practices and artifacts to give a better understanding and nature of pre-service teachers' TPACK development. Although self reported measures did not correlate with pre-service teachers' actual increased knowledge of technology integration, this study enhances better understanding of the pre-service teachers' TPACK development through the multiple assessment measures. The learning outcome measures provide specific information and concrete representation of what pre-service teachers can actually do with technology in their TPACK development. The findings suggested multiple concerns about self-reported measures that are discussed in the framework of the TPACK instrument.

Keywords Pre-service teachers · Technology · Pedagogy · Content knowledge Technology integration

1 Introduction

According to Shulman (1986), the specific nature of teachers' knowledge is notoriously difficult to discern, much less assess, with accuracy. It is situated, socially constructed, and highly complex (Shulman 1987). Recent studies (Koehler and

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Mishra 2008; Mishra and Koehler 2006) however, have employed TPACK—Technological Pedagogical Content Knowledge framework—(Mishra and Koehler 2006) as a useful organizational structure in describing and assessing teachers' knowledge and skills related to technology integration. Hofer et al. (2011) reported that using a construct such as TPACK to conceptualize teachers' technology integration knowledge requires reliable strategies to assess that knowledge in the many forms in which it appears.

Pedagogical Knowledge (PK) includes generic knowledge about how students learn, teaching approaches, methods of assessment and knowledge of different theories about learning (Harris et al. 2009; Shulman 1986). Technology Knowledge (TK) broadly encompasses knowledge of standard technologies such as books and chalk and blackboard, as well as more advanced technologies such as the Internet and digital video, and the different modalities they provide for representing information (Polly et al. 2010). A consideration of P and C together results in Pedagogical Content Knowledge (PCK). This is similar to Schulman's (1987) idea of knowledge of pedagogy that is applicable to the teaching of specific content. This includes representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students prior knowledge and theories of epistemology (Koehler et al. 2007). Technological Content Knowledge (TCK) refers to knowledge about how technology may be used to provide new ways of teaching content (Niess 2005).

Technological Pedagogical Knowledge (TPK) refers to knowledge about the affordances and constraints of technology as an enabler of different teaching approaches (Mishra and Koehler 2006). Technological Pedagogical Content Knowledge (TPACK) is the knowledge and understanding of interplay between the three elements (CK, PK and TK), when using technology for teaching and learning (Schmidt et al. 2009). According to Koehler et al. (2007), good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate, context-specific, strategies and representations. Thus besides understanding and developing knowledge related to TPACK, it is important for teachers to understand the "Context" in which technology is integrated (Harris et al. 2009).

Koehler and Mishra (2008) stated that TPACK, like all types of knowledge is expressed in different ways and to different extents at different times with different students, and in differing contextual condition. Knowledge of technology cannot be treated as context-free, unrelated and separate from knowledge about teaching tasks (Hughes 2005; Koehler and Mishra 2009; Zhao 2003). New understanding of the complex, situated, and interdependent nature of TPACK (Mishra and Koehler 2006; Koehler and Mishra 2008) has led to inevitable questions about how this knowledge can be assessed. Roblyer and Doering (2010) recommend TPACK self-assessment as the first step in each stage of instructional decision-making. Many other studies have also shown that measured gains in teachers' self-assessed knowledge over time are more reflective of their increased confidence regarding a particular professional development than their actual increased knowledge in practice (Lawless and Pellegrino 2007; Schrader and Lawless 2004). Self-report data should therefore be triangulated with external assessments of teachers' TPACK knowledge (Roblyer and Doering 2010; Kereluik et al. 2010).

2 Theoretical framework

Literature has shown that different types of data can be used to assess teachers' TPACK: self-reports (e.g. survey responses, interviews, reflexive journal entries), observed behaviour (e.g. classroom observations) and teaching artifacts (eg. teacher lesson plans). According to Hofer et al. (2011), many recent TPACK assessments are based primarily upon self-reported survey data, whether focused on teachers' technology proficiency (e.g., Ward and Overall 2010), self efficacy (e.g., Lee and Tsai 2010), technology adoption concerns and/or stages (e.g., Williams et al. 2010), perceptions of necessary knowledge (e.g., de Olvieira and Romero 2010; Robertshaw and Gillam 2010), or evaluations of TPACK-based learning experiences (e.g., Zhou et al. 2010). Kereluik et al. (2010) reported that while self-reported surveys provide important information about an individual's TPACK awareness, such data are limited to measuring individuals' beliefs. Similarly Archambault and Barnett (2010) noted: "although a survey methodology is appropriate when seeking to examine characteristics from a given population, it is not as accurate as actual observable behaviour" (Archambault and Barnett 2010, p.1661).

Harris et al. (2010) also indicated that inferring a teacher's TPACK solely by direct observation in the classroom is probably not possible, since the decision-making processes that led to the observed instructional actions and interactions need to be identified so that the knowledge that undergirds those actions and interactions can be discerned. Shin et al. (2011) made clear that many studies reported a combination of different measures to be able to draw conclusions from different perspectives. For example, Stoilescu and McDougall's (2010) ethnographic study of mathematics teachers' technology integration incorporated similar data types and sources, but in a more immersive and contextually based way typical of modern anthropological research.

Doering et al. (2009) argue that TPACK needs to be assessed from different views to help in a holistic assessment of teaching with ICT. Increasingly, multiple-method assessments of teachers' technology integration knowledge have been attempted in an effort to uncover and understand more of the complexity inherent in the interdependence and situatedness of the TPACK construct (Hofer et al. 2011). The complexity mentioned by different researchers (Angela and Valanides 2009; Borko et al. 2008; Koehler and Mishra 2008; Mishra and Koehler 2007; Mishra and Koehler 2006) is due to inconsistencies between teachers' perceptions (i.e. what they think) and their classroom practices (i.e. what they do).

3 Developing TPACK in an instructional technology course

This research was conducted in the context of the department of science and mathematics education in a major teacher preparation program in Ghana. The 14-week course required pre-service teachers to attend 1–2 h lectures and 1–2 h laboratory sessions per week. The technological knowledge learned by the pre-service was spreadsheet applications for mathematics, because it has potential for supporting students' higher-order thinking in mathematics. It is user friendly (Niess et al. 2007), and readily available in senior high schools and in teacher education colleges (Agyei and Voogt 2012). The content knowledge was mathematics, which was the pre-service teachers' teaching subject area, and the pedagogical approach was not specified. Table 1 presents an overview of the activities in the IT course in relation to strategies for developing TPACK.

4 Method

4.1 Research questions

The following research questions guided this study:

1. How do pre-service teachers demonstrate their TPACK competencies through learning outcomes and how are these outcomes related?
2. How are the TPACK learning outcomes of the pre-service teachers related to their self-reported TPACK?

4.2 Participants

One hundred and four pre-service mathematics teachers participated in the study. The pre-service teachers were in their final year of the mathematics teacher education programme at the University of Cape Coast (UCC). The pre-service teachers did not have any experience in technology-supported

Table 1 Instructional technology course and strategies for technology integration

DT activities	Activity	Integration competencies	Time frame
Introduction to technology-based possibilities of teaching mathematics	l/ls	TPACK	4 weeks
Introduction to learning by design (collaboration)	l	–	
Introduction to computer skills(and spreadsheets in particular)	l/ls	TK	
Introduction to TPACK concept	l	TPACK	
Introduction to learner centred approaches	l	PK /PCK	
Introduction/demonstration of learner-centred based lessons supported by spreadsheet (exemplary material) and discussion	l/ls	TPACK	
Scouting spreadsheet techniques that support mathematics teaching	ls	TPK	5 weeks
Development of mathematics activities supported by spreadsheets and lesson development	ls	TCK	
Teaching of learner-centred based lessons supported by spreadsheets to peers/researcher	ci	TPACK	5 weeks
Revision of the developed lesson materials based on feedback	ci/ls	TPACK	

l lecture; *ls* laboratory session; *ci* classroom implementation lessons or any relevant training in their pre-university education at the SHS. The participants were made up of 70 males and 34 females aged between 19 and 37 with the average age of nearly 25 years.

4.3 Instruments

Five different instruments were used in this study to assess the learning outcomes and the TPACK development of the pre-service teachers. Table 2 provided a general overview of the different instruments used, their purpose, and stage of administration during the Instructional Technology (IT) course.

4.4 TPACK lesson plan rubric (TLPR)

A TPACK lesson Plan rubric was adapted from the Technology Integration Assessment Rubric (TIAR) which Harris et al. (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 to TPACK for spreadsheet-supported lessons 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 maximum 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 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 program. Interrater reliability (Cohen's κ=0.90) was calculated using a sample of three lesson plans.

Table 2 Overview of instruments and their stages of administration

Instrument	Purpose	Measurement type	TPACK data		Stage of administration		
			Source	Type	B	M	E
Lesson plan rubric	Assess the quality of technology integration lesson	Performance assessment	Team	Teaching artifact		✓	✓
TPACK observation rubric	Assess the ability to apply TPACK in real teaching practice	Performance assessment	Team	Observable		✓	✓
Product evaluation rubric	Assess the fit (quality) of the various components of the designed product	Performance assessment	Team	Teaching artifact		✓	✓
ICT skill test	Assess ICT skill	Performance assessment	Individual	Observable	✓		✓
TPACK survey	Assess self-reported TPACK	Survey	Individual	Self-reported	✓		✓

**B* before, *M* mid, *E* end of Instructional technology course

Table 3 TPACK lesson plan rubric

Appropriately spelt out subject matter of Mathematics lesson *(CK)*
ABL strategies support to mathematics learning *(*PK*)*
Clearly designed spreadsheet techniques that can support transfer of knowledge *(TK)*
Support of learner-centered strategies to mathematics lesson goals (*PCK)*
Alignment of spreadsheet techniques to mathematics lesson goals *(TCK)*
Support of spreadsheet to learner-centered strategies *(TPK)*
Fit of mathematics content, learner-centered strategies and spreadsheet techniques together within the instructional plan *(TPACK)*

4.5 TPACK observation rubric

The Observation Rubric was adapted from a valid and reliable TPACK-Based Technology Integration Observation Instrument (Hofer et al. 2011) that was developed and used to assess TPACK evidence in observed instruction. Adaptations were made to be able to observe TPACK for spreadsheet-supported lessons 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 mid and end of the program respectively. Cohen's κ for two independent raters was 0.94. Table 4 gives an overview of sample questions for each TPACK knowledge type construct that was assessed in one of the lessons: Enlargement with scale factor *k*.

4.6 TPACK final product rubric

Each finished product of the DTs consisted of a teacher's guide (which provides an overview of the designed material as well as steps in preparing and setting up the technology-designed lesson environment) , lesson plan (contains procedural specifications to support teachers in developing and executing the lesson), student's worksheet (contained designed activities that student do alongside the lesson execution) and Presentation Slide (provided a visual aid to enhance understanding of content) for instructional purposes. Each criterion was up to 3 marks with a maximum score of 12. Cohen's kappa coefficient was $\kappa=0.93$. The DT final product was evaluated according to a rubric provided in Table 5.

4.7 ICT skill test

An ICT skill performance test developed by the researcher to assess the students' level of ICT skills was administered two times: before and after the IT course. The instrument consists of 40 objective items that assessed different basic ICT skills such as: Windows operating systems, Microsoft office applications and Internet usage. The test was reviewed by two educational technology experts and the reliability of the test was $\alpha=0.79$.

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 $\boldsymbol{k}$ is the ratio of the image to the object. $\left(k = \frac{\text{image size}}{\text{object size}}\right)$.	✓		
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)($TPCK_{maths}$)		✓	

4.8 TPACK survey

The questionnaire included items that addressed teachers' self-assessment toward TPACK adapted from Schmidt et al (2009) on a five-point likert scale format (from 1-strongly agree to 5-strongly disagree). Construct validity analysis of items from the framework ranges from 3.67 to 9.00 of the knowledge types, with five of the seven types scoring 7.88 (Schmidt et al. 2009). Cronbach's alpha reliability estimate of this instrument ranges from 0.75 to 0.93 (Schmidt et al. 2009). The instrument was administered two times: before and after the IT course. Teachers' responses in the

Table 5 Criteria for analysing final product

Criteria	Very good (3)	Good (2)	Satisfactory (1)	Not at all (0)
Process skill/ Task	Teacher's Guide optimally supports setting the ICT-designed lesson	Teacher's guide supports setting the ICTdesigned lesson	Teacher's guide minimally support setting the ICT-designed lesson	Teacher guide does not support setting the ICT-designed lesson
Screen organization/ appeal of display	Organization of Presentation slides aligns very well with the given subject matter	Organization of Presentation slides aligns with the given subject matter	Organization of Presentation slides minimally aligns with the given subject matter	Organization of Presentation slides do not align with the given subject matter
Designed activities/ student worksheet	Activities designed align very well with Instructional objectives in the given topic	Activities designed align with Instructional objectives in the given topic	Activities designed minimally align with Instructional objectives in the given topic	Activities designed do not align with Instructional objectives in the given topic
Overall fit (Teacher guide, lesson plan, slides & student worksheet)	Teacher guide supports Lesson plan, slides and student worksheet fit very well together	Teacher guide supports Lesson plan, slides and student worksheet fit together	Teacher guide supports Lesson plan, slides and student worksheet fit minimally together	Teacher guide does not support Lesson plan, slides and student worksheet fit

Adapted from Harris et al. (2010)

pre-post survey delineated expressed beliefs about teachers' disposition toward ongoing evolving understanding of the subscales (Table 6).

4.9 Data analysis

To analyze the data descriptive statistics, paired-samples t-tests, and correlation analysis were used. Correlation coefficients of 0.10, 0.30 and 0.50, irrespective of

Table 6 Sample question for each TPACK knowledge type constructs

Knowledge type	Sample question for each knowledge type
TK	I know about a lot of different technologies
CK	I have sufficient knowledge about mathematics
PK	I can adapt my teaching style to different learners
PCK	I know how to select effective teaching approaches to guide student thinking and learning in science
TCK	I know about technologies that I can use for understanding and doing science
TPK	I can choose technologies that enhance the teaching approaches for a lesson
TPACK	I can teach lessons that appropriately combine mathematics, technologies, and teaching approaches

the sign, were interpreted as small, medium and large respectively (Green and Salkind 2008). Effect size was calculated using Cohen's d (Cohen 1988). Cohen (1988) provided tentative benchmarks for the interpretation of effect sizes. He considers d=0.2 a small, d=0.5 a medium and d=0.8 a large effect size. Cohen's Kappa coefficient (κ) was calculated to estimate the degree of agreement among different ratters of research instruments. Landis and Koch (1977) proposed a schema for interpreting κ values: κ<0 for poor agreement; 0 to 0.20 slight agreement, κ=0.21 to 0.40 a fair agreement, κ=0.41 to 0.60 a moderate agreement; κ=0.61 to 0.80 a substantial agreement; and κ=0.81 to 1.00 a perfect agreement.

5 Findings

5.1 Evaluating the lesson outcomes

Table 7 shows pre-service teachers' TPACK competencies expressed in learning outcomes after working in DTs.

The respondents' pre- and post-test means for all four measures indicate significant changes in all TPACK-related learning outcomes with largest areas of change occurring in the pre-service teachers' final designed product. The results and insights learned from the teaching try-outs (classroom implementation) served as necessary inputs for the teachers in revising their designs. As a result their final designs reflected TPACK competencies. The insights learned were perceived both in the observable and teaching artifacts. Specifically, their final product contained improved and well-developed lesson plans to guide class instruction. Lesson plans improvements were reflected in areas such as: clearly spelt out lesson objectives, well defined roles for both the teacher and students and clearly spelt out timings for various sections of the lesson.

Designed lesson activities were also improved immensely correlating very well with the lesson plans, and presentation slides. Regarding the final observed lessons, pre-service teachers improved their pedagogical strategies reflecting more learner-centeredness with the use of technology. The teachers used their improved spreadsheet-supported lessons to engage their students better in different learning related activities (e.g., view a presentation, collect data, make predictions) including group task using their students' worksheet. Table 8 gives a summary of examples of pre-service teachers' finalised technology-enhanced lessons that they taught, indicating the role of technology in the teaching and learning process.

In spite of some difficulties (eg. designing authentic learning activities for selected topics with the appropriate spreadsheet applications) in applying their knowledge to

Table 7 Pre- and post-test mean score responses for pre-service teachers' learning outcomes

Measure	Min-Max	Pre mean (SD)	Post mean (SD)	*P*	Effect size
Lesson plan score	7–21	15.00 (1.22)	16.76(1.37)	0.000	1.35
TPACK observation score	20–60	36.13 (3.57)	42.25 (4.89)	0.000	1.43
Product evaluation score	0–12	7.53 (0.79)	9.08(0.83)	0.000	1.92
ICT skill test score	0–40	27.53(4.81)	31.63(3.70)	0.000	0.95

Table 8 Technology-enhanced lessons with the added value of technology

Lesson	Teaching and learning activities	Added value of technology
Polynomial Functions (Year 2)	Collaboration in teams to explore patterns, team presentations and peer assessment	Changing variables in cells (spreadsheet environment), a wide range of examples of graphs are demonstrated without having to draw them physically; learners are able to explore many more cases in a shorter time, giving them greater opportunity to consider general rules and test and reformulate hypotheses
Plane Geometry (Year 1)	Interactive demonstration with students, collaboration in teams to explore relationships/properties of figures	Technology use in an interactive demonstrative lecture stimulates discussion. Visual representations of geometrical figures allows for immediate feedback, allowing learners to concentrate more on mathematical relationships rather than on the mechanics of construction
Statistics (Year 2)	Students view presentation, make predictions, collect data and interpret them in teams	Using the spreadsheet allow for many numerical calculations simultaneously, easy tabulation of numerical data, graphical representation of the data, analyses and exploration of number patterns
Simultaneous Linear Equations (Year 1)	Interactive demonstration with students, group tasks and group presentations	Spreadsheet allows for solving equations numerically and graphically providing a visual link between algebraic solution for the intersection of two straight lines and their graphical representation; “zooming” in and out allows in-depth investigation of points of intersection

teach the technology-enhanced lesson, the arrangement impacted on the teachers’ beliefs and confidence (expressed in the learning outcomes) in representing mathematical concepts with technology in pedagogically sound ways.

To assess the degree of linear relationships among the variables, correlation analyses were conducted for measures of learning outcomes: Lesson Plan score, TPACK Observation score, Product Evaluation score (mid-measures of the intervention) and Lesson Plan score, TPACK Observation score, Product Evaluation score, ICT Skill test score (post-measures). In general the results suggest that an increase or gain in any one of the pre-service TPACK related measures tend to increase the other measures except for the ICT skill test measure. Table 9 shows that the correlations for the mid measures were statistically significant with large coefficients (their correlation coefficients in the post measure were slightly higher though).

The ICT skill test measure (post) did not correlate with any other learning outcome measure.

The scatterplots in Fig. 1 gives a visual representation of the relationship between these measures.

The relationship between the ICT Skill test measure and the various learning outcomes followed similar trend and seemed to be non-linear although that was not what one would expect.

Table 9 Pearson correlation matrix among learning outcomes

	Lesson plan score	TPACK observation score	Product evaluation score
Lesson plan score	1.000		
TPACK observation score	0.852** (M) 0.992** (P)	1.000	
Product evaluation score	0.944** (M) 0.944** (P)	0.940** (M) 0.992** (P)	1.000

**Correlation is significant at the 0.01 level (2-tailed); (M mid, *P* post measures)

Two possible reasons can be inferred from the plot: 1) some extreme scores (outliers) might have overly influenced the correlation co-efficient (i.e. lowering it) and or 2) the distribution of the ICT test scores could have fallen within a restricted interval (i.e. not making the distribution normal). Both reasons have implications on test scores (or items) and need further exploration.

5.2 Self-reported measures and the learning outcomes of TPACK

The results indicate significant changes in all components of TPACK self-reported measure with largest areas of change occurring in subscales related to technology integration: TPACK (2.80), TCK (2.44), TPK (2.31) and TK (2.31) which participants might have found as entirely new experiences (Table 10).

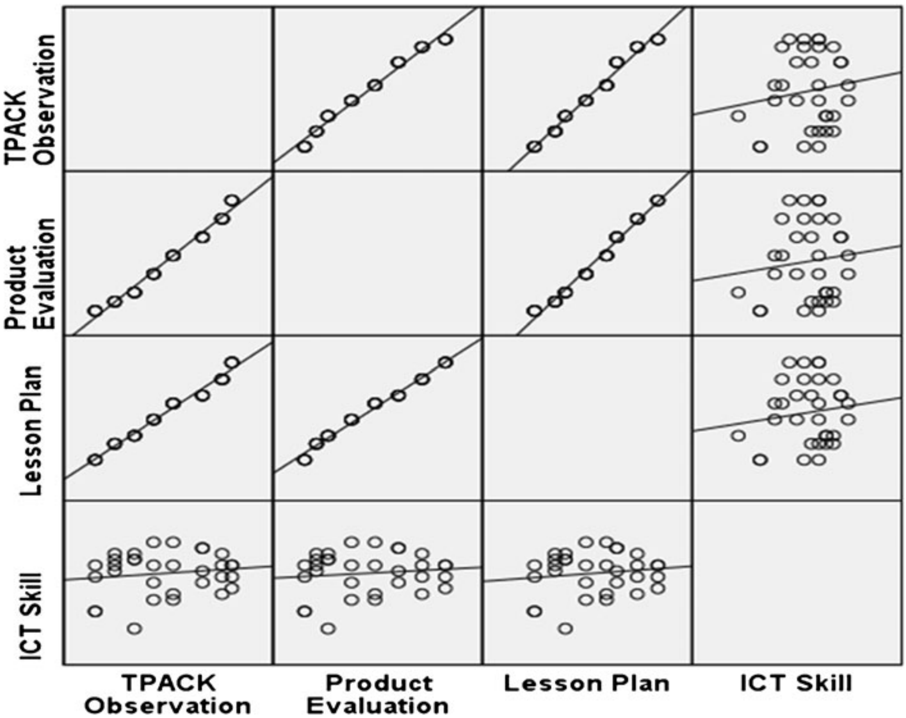

Fig. 1 Scatter plot matrix of learning outcome measures

Table 10 Results for pre- and post-test mean score responses for TPACK subscales

Factor	Pre mean (SD)	Post mean (SD)	*P*	Effect size
TK	2.74 (0.72)	4.11(0.44)	0.000	2.31
CK	4.10 (0.58)	4.52 (0.47)	0.000	0.79
PK	4.08 (0.44)	4.51(0.41)	0.000	1.01
PCK	3.71(0.84)	4.47(0.53)	0.000	1.07
TCK	2.34 (1.04)	4.34(0.51)	0.000	2.44
TPK	3.06 (0.77)	4.44(0.40)	0.000	2.31
TPACK	2.38(0.92)	4.40(0.45)	0.000	2.80

Based on the pre-test of the TPACK survey, the correlations among the different TPACK domains were explored. Whereas some domains (eg. PK and TPK) showed weak correlation coefficients, some showed medium (CK and TCK) and others large (TPK and TPACK). Some domains (PK and TPACK) did not correlate at all, while others (PCK and TPACK) showed a negatively weak correlation. Correlation coefficients that were significant were observed at the 0.05 significant levels. The results suggest that pre-service teachers were not probably able to integrate the different domains in their thinking about ICT integration in teaching before the instructional technology course.

The post-test measure however gave a better picture of interdependence of the various TPACK components. The results showed that TK, PK, CK and all their intersections were positively correlated with large correlation co-efficient at 0.01 significant levels. The largest co-efficient (0.82) was between TPK and TPACK and the least (0.503) between TK and PCK (Table 11).

When correlating the TPACK self-reported measure with learning outcomes, significance correlation was found only between ICT skill test score and TK (Tables 9 and 12).

6 Discussion

This study draws conclusions from different perspectives with a combination of various measures to investigate their effectiveness associated with assessing pre-service teachers' TPACK. Self-report data were triangulated with performance-based assessment measures (Lesson Plan score, TPACK Observation score, Product Evaluation score and ICT Skill Test) of pre-service teachers' TPACK in a mathematics-specific IT course that focused on preparing student teachers to integrate technology in their future classrooms. Findings showed that in spite of design challenges, their technology integration competencies improved as were reported in their self-reported and learning outcome measures after the teachers' participation in the course.

While the self-reported measure assessed pre-service teachers' perception and awareness of TPACK (perceived ability to integrate technology), the performance-based assessment measures assessed knowledge the pre-service teachers had developed (what they were essentially able to do). For example pre-service teachers' final

Table 11 Pearson correlation matrix for TPACK domains

	TK	CK	PK	PCK	TCK	TPK	TPACK
TK	1.000						
CK (pre)	0.414**	1.000					
(post)	0.614**						
PK (pre)	0.401**	0.545**	1.000				
(post)	0.541**	0.707**					
PCK (pre)		0.500**	0.525**	1.000			
(post)	0.503**	0.707**	0.766**				
TCK (pre)	0.426**	0.340**	0.430**	0.319**	1.000		
(post)	0.594**	0.584**	0.521**	0.537**			
TPK (pre)	0.423**		0.249*		0.600**	1.000	
(post)	0.631**	0.716**	0.690**	0.595**	0.806**		
TPACK (pre)				−0.247*	0.431**	0.657**	1.000
(post)	0.556**	0.592**	0.595**	0.578**	0.718**	0.820**	

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

designed lesson product included well developed instructional components (with technology) that described the sequence of events making up the lesson including the teachers' instructional input and guided practice their students will use to try out new concepts and ideas. Their evolving observed lessons were less teacher-centred in which technology was used to facilitate active learning; promoting collaborations, making students' learning more engaging and interactive.

Pre-service 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, helping their students explore mathematics concepts and perform authentic tasks. This was confirmed by their perceived development in the knowledge needed to design and enact spreadsheet-supported lessons as were observed by significant gains in all the TPACK components of the teachers' self-reported data.

Table 12 Pearson correlation coefficient between TPACK domains and learning outcomes

Domain	Lesson plan score	TPACK observation score	Product evaluation score	ICT skill test score
TK	0.299	0.248	0.290	0.349*
CK	0.297	0.242	0.252	0.290
PK	0.212	0.171	0.168	0.280
PCK	0.093	0.023	0.064	0.173
TCK	0.331	0.263	0.304	0.201
TPK	0.294	0.224	0.260	0.176
TPACK	0.201	0.171	0.188	0.160

*Correlation is significant at the 0.05 level (2-tailed)

Teachers perceived that their knowledge and skills had developed more in areas where the 'T' is involved compared to their PK, CK and PCK. The teachers' initially rated themselves high on PK and PCK, but after having experienced the potential of learner-centred lessons might have realized that they never had considered other pedagogical approaches than the ones they were used to. The findings also indicated that the teachers initially rated their CK as high, but expanded their own understanding of mathematical concepts as they explored the spreadsheet-supported learner centred lessons pedagogical approach. Thus, findings of the study suggest that as novice teachers, the new experience with spreadsheet and learner-centred approach impacted on their knowledge regarding all the TPACK constructs. Correlations between the TPACK learning outcomes were statistically significant with large correlation coefficients indicating that these measures could be used interchangeably in determining pre-service teachers' TPACK. The ICT skill test measure, however, did not correlate, with any other learning outcome measures.

Regarding the self-reported TPACK survey, it appears that, the pre-intervention correlations among the different TPACK domains were not well situated; post measures, however, showed very high correlations indicating strong and interdependent connections between all the components of TPACK. This indicates that the pre-service teachers' TPACK was strengthened and did further develop as the course progressed, giving them a more integrative view of TPACK. This finding is in line with multiple studies which argue that knowledge of technology cannot be treated as unrelated and separate from knowledge about teaching tasks and that conceptualization of TPACK goes beyond seeing content, pedagogy, and technology as constructs in and of themselves (Koehler and Mishra 2009; Hughes 2005; Zhao 2003); but there exist a dynamic and transactional relationship between them (Koehler et al. 2007). However, the self-reported TPACK measure did not correlate with measures of learning outcomes apart from what was observed between TK and ICT skill test.

Although numerous studies have shown that what teachers think they know or can do (their self-efficacy) do not necessarily align with what they really know or do in practice (Harris et al. 2010; Lawless and Pellegrino 2007), several other studies about the relation between self-efficacy and actual teacher behaviour have shown that self-efficacy is a good predictor for actual teaching behaviour (e.g. Tschannen-Moran and Hoy 2001). For this reason, it would be expected that a possible linear relationship between self-reported components of TPACK and the TPACK learning outcomes exists as was observed in TK (which assess perceived competencies in using various ICT applications) and ICT skill (which assess basic ICT skill competencies).

In our assessment, the context-related factor is a possible explanation for the absence of significant relations between the measures. The learning outcome measures assessed the pre-service teachers' use of technology-specific (spreadsheet) in particular in teaching subject-specific (mathematics) lessons. The TPACK survey on the other hand, with its potential wide applicability in different context and technologies might have been applied on a more generic and abstract level. Evidently, the pre-service teachers were unable to apply the instrument in their subject matter area and in their use of the given technology. This confirms previous studies which argue that knowledge of technology cannot be treated as context-free (Hughes 2005; Koehler and Mishra 2009) and that in understanding and developing knowledge related to TPACK, it is important for teachers to understand the context-specific, strategies and representations in which technology is integrated (Harris et al. 2009; Koehler et al. 2007).

7 Conclusion

Although the pre-service teachers' learning outcome measures did not correlate with their self-reported TPACK measure, the results of the study gave a better picture and understanding of pre-service teachers' TPACK development through multiple-method assessment of teachers' technology integration knowledge which is consistent with numerous studies (Doering et al. 2009; Hofer et al. 2011). While the study does not undermine self-report surveys as useful measures in providing important information about individuals' TPACK awareness and their reflection of increased confidence, the researchers advocate the use of learning outcomes by which pre-service teachers can demonstrate their TPACK. Such learning outcome measures provide specific information and concrete representation of pre-service teachers' TPACK and what they can actually do with technology to enhance teaching and learning. In situations where self-reported data are unavoidable, researchers should take measures to ensure triangulation through the use of multiple data sources, multiple data methods and involvement of multiple coders in the analysis of qualitative data to ensure validity and reliability of results. Besides developing and assessing teachers' knowledge related to TPACK with diverse measures, it is important to pay attention to the specific context in which technology is integrated particularly when using self-assessed TPACK instruments.

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