

Using Technology in Mathematics: Professional Development for Teachers

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The Ghanaian mathematics curriculum expects teachers to adopt technologies as an instructional tool to assist students to learn mathematics relationally. Teachers' dispositions (knowledge, beliefs, and attitudes) towards technology are critical in translating the curriculum intention into practice. This paper presents teachers' initial dispositions related to technology integration and their views about a professional development model. In this model, they worked in teams to develop and enact GeoGebra-based mathematics lessons with support from expert, exemplary materials, and demonstration lessons. The results indicate that the model of professional development is promising in engaging teachers in technology integration.

The mathematics curriculum for Ghana's senior high school students (15-17 years) emphasises the need for teachers to assist students to use computers, calculators, and spreadsheets to develop mathematical concepts, and to investigate and solve real life problems (CRDD, 2007). Though not explicitly stated, the general objectives outlined in this curriculum suggest the use of these technologies mediate constructivist teaching and learning approaches where students are guided to use tools to explore mathematics concepts relationally. However, lack of subject-focused technological knowledge and skills impede teachers' ability to use technologies in their classroom (Agyei & Voogt, 2012).

Considering the technology adoption policy in the mathematics curriculum for senior high schools and the fast-changing nature of technology, a necessary condition for effective implementation of these technologies is the teachers' dispositions (knowledge, beliefs, and attitudes) related to the use of technology. Teachers need to have knowledge about technology, content, curriculum, teaching approaches, classroom management, learners and their characteristics, assessment of student learning, and ways to evaluate instructional approaches (Webb & Cox, 2004). Consistent with this argument is the Technology, Pedagogy, and Content Knowledge (TPCK) theoretical framework proposed by Mishra and Koehler (2006). Mishra and Koehler espoused that teachers need a well-developed integrative knowledge of technology, pedagogy, and content for effective technology adoption in the classroom. A professional development model, where teachers are engaged in technology-oriented activities is one of the key steps to enhance teachers' knowledge and skills to use technologies to teach mathematics (Koehler, Mishra, & Yahya, 2007; Koellner, Jacobs, & Borko, 2011).

Theoretical Underpinnings

The TPCK framework guided the content and structure of the professional development model proposed in this research study. The tenets of the TPCK framework espoused that the knowledge and skills which the teachers are required to adopt depend on the contextual understanding of the interconnected ideas between technology, pedagogy, and content knowledge. Technology knowledge (TK) is the knowledge about how to use ICT hardware and software and associated peripherals. Technology content knowledge (TCK) is the knowledge about how to use technology to represent and create the subject content in different ways. Technology pedagogy knowledge (TPK) is the knowledge to choose a technological tool based on its fitness for the learning activity. Technology pedagogy content knowledge (TPCK) is the knowledge of using technological resources based on their appropriateness to teaching and learning tasks of specific subject content (Mishra & Koehler, 2006).

Hechter, Phyfe, and Vermette (2012) argue that “the application of technological, pedagogical, and content knowledge principles should be understood under the broad contexts of school environments, individual teachers’ previous experiences, and epistemological beliefs about teaching and learning” (p. 141). Although Mishra and Koehler (2006) acknowledged the relevance of context (which include teachers’ working environment and their personal orientations-prior experiences, beliefs, and attitudes) in effective implementation of technology, this component is less explored in most of the TPCK research studies (Chai, Koh, & Tsai, 2013). For teachers to appreciate the constraints and maximise the affordances of technology, it is argued in this paper that their technology integration knowledge needs to be developed alongside their beliefs and attitudes related to the use of technology (Ertmer & Ottenbreit-Leftwich, 2010). Attitude is defined in a psychological sense to encompass teachers’ affective, cognitive, and behavioural attitudes related to technology integration. The affective attitude is the feeling (either comfortable or dislike) the teachers have about the use of technology (e.g., technology makes me feel comfortable). Teachers’ cognitive attitude is the belief (either personal or pedagogical) about technology importance (e.g. Using technology in class will make my students learn independently). Teachers’ behavioural attitudes is their intention and willingness to use technology in future (e.g., I would rather use technology to illustrate mathematical concepts to students than chalk-board illustrations) (Christensen & Knezek, 2008; Albirini, 2006).

Teachers’ dispositions can be enhanced if they work collaboratively in design teams that involve at least two teachers from the same or related disciplines (Koehler, Mishra, & Yahya, 2007). These design teams come together on a regular basis with the common aim to redesign and enact their common curriculum. Empirical studies have demonstrated the significance of this approach in developing teachers’ knowledge, beliefs, and attitudes. Kafyulilo, Fisser, and Voogt (2015) adopted teacher design teams as a professional development approach for developing technology knowledge and skills among in-service science teachers. They supported teachers with demonstration lessons, exemplary materials, and expert assistance. The pre-and post-test measurements indicated significant improvement in teachers’ technology integration knowledge and skills. In a similar study, Agyei and Voogt (2012) found that four pre-service teachers developed their TPCK better when they worked in groups of two to design spreadsheet-based lessons and subsequently taught those lessons to their peers.

From the foregoing discussion, it appears that teachers develop their technology integration knowledge (TPCK) and beliefs and attitudes through a professional development model involving design and enactment of lessons by design teams, provision of expert’s

support, use of specific mathematics software applications, and use of exemplary materials. Hence, this professional development model was adapted in this research study to achieve two purposes: to gain an understanding of teachers' initial disposition of technology integration; second, to examine their views about the professional development model where they worked in groups to develop and teach technology-based mathematics lessons. GeoGebra was proposed for use in this professional development model because it is open software and is readily available and user friendly. It also has the potential to enhance teachers' knowledge and skills of using technologies to mediate constructivist teaching approach where students are engaged in higher-order mathematical thinking (Prodromou, Lavicza, & Koren, 2015).

Method

To achieve the two purposes stated above, the following research questions were addressed:

- What are teachers' dispositions (knowledge, beliefs, and attitudes) related to technology integration in mathematics?
- What are the views of the teachers about the professional development model where they are working in groups to develop and teach technology-based mathematics lessons?

This research study employed case study design rooted in an interpretive approach where eleven (two females and nine males) teachers in the mathematics department of a Senior High School in Ghana voluntarily participated in a one-year professional development model involving the use of technology in mathematics at their own school. The age of the participant teachers ranged from 25 to 45, and their teaching experience ranged from 1 to 20 years. The participant teachers' knowledge, beliefs, and attitudes about the use of technology in mathematics were explored through semi-structured interviews, self-report questionnaires, lesson plans developed by the teachers, and lesson observation. A questionnaire and a semi-structured interview approach involving informal conversation and interview guide were used to collect preliminary data on teachers' demographic information and their experiences of using technology to teach mathematics. The teachers were interviewed individually. Each interview lasted not more than 45 minutes and it was audio recorded. The initial understanding of teachers' technology disposition helped the first author adapt a professional development model to their needs.

A workshop was designed where teachers were introduced to the concepts of the TPCK framework and learning technology by design. This provided the teachers with the theoretical grounding of including technologies in their pedagogical decisions as well as appreciating the constraints and affordances of using technologies in their working environment. The teachers were introduced to geometric, constructing, and algebraic tools in GeoGebra. This provided them with the specific technological knowledge they required to integrate technologies into their classroom practices. The teachers were supported with exemplary materials and expert's assistance. The exemplary materials were in the form of GeoGebra tutorials (which provided the teachers the introductory knowledge and skills of using the geometric, algebraic, and constructing tools in GeoGebra), exemplary lesson plans (which served as basis for pedagogical reflection and replication), and the GeoGebra online community (which served as a platform to borrow existing mathematics lesson for classroom use). The first author provided expert support to the teachers. He developed four GeoGebra-based lessons, two of which he taught as a demonstration. The teachers worked in design teams of two to three members to develop GeoGebra-based mathematics lessons. They first

taught those lessons to their peers and subsequently expected to teach those lessons to students in their actual classrooms. The teachers were engaged in discussion after each teaching rehearsal to critically reflect on the best knowledge, classroom practices, and teaching experiences (Koellner, Jacobs, & Borko, 2011).

A TPCK self-report questionnaire was adapted from Schmidt, Baran, Thompson, Mishra, Koehler, and Shin (2009), which is reported as having a Cronbach alpha reliability coefficient ≥ 0.8 across the various TPCK constructs. The items on teachers' affective attitudes, cognitive attitudes, and behavioural attitudes were adapted from Albirini (2006), which is reported as having a Cronbach alpha reliability coefficient of 0.9. Teachers' perceived benefit of learning technology by design team approach was determined through self-report questionnaire adapted from Koehler and Mishra (2005). All the items on the questionnaires consisted 5-point Likert scale (strongly disagree = 1, to strongly agree = 5), where 1 is interpreted as the lowest possible score which represents a very strong negative response, and 5 is the highest possible score which represents a very strong positive response about technology integration in mathematics.

Mean scores and standard deviations were employed to determine the level of teachers' technology integration knowledge, beliefs and attitudes related to technology usage in mathematics teaching. The audio-recorded interviews were analysed to identify themes and patterns in relation to the theoretical background, purpose, and the research question of the study. The interview data was triangulated with the questionnaire and the observation data. In cases where teachers' views were quoted in this report, their names were altered.

Results

Teachers' Initial Beliefs, Attitudes, and Knowledge Related to Technology Integration

The results in Table 1 indicate that at the outset of the professional development model, the participant teachers had relatively high notions of the effectiveness of technology in mathematics education. All teachers indicated that technology could enable new instructional approaches where students can concretise mathematical ideas through dynamic pictures and videos. Joseph highlighted, "using technology makes teaching simple as students can visualise the mathematics concepts and make out their own meaning".

Table 1
Teachers' Perceived Beliefs and Attitudes Related to Technology Integration

Perceptions	Example	Mean (SD)
Personal belief	Using technology in class can raise student performance.	4.40 (0.39)
Pedagogical belief	Using technology in class will make my students learn independently.	3.81 (0.49)
Affective attitude	Technology makes me feel comfortable.	4.15 (0.40)
Cognitive attitude	I think I need technology in my classroom every day.	3.95 (0.39)
Behavioural attitude	I would rather do things by technology than with my hand.	4.73 (0.24)

With regards to teachers' knowledge of technology integration (TPCK), the results in Table 2 indicate that majority of the participant teachers have a relative limited knowledge of technology integration. For instance, more than half of the teachers were less aware about the existence of teaching and learning mathematics software such as Derive, Geometer's Sketchpad, Inspiration, Macromedia Authorware, Green Globe, GeoGebra and Graphmatica. At most they used the software such as Microsoft Word for typing end of term examination questions and SPSS, Matlab and Microsoft Excel for recording students' continuous assessment. For instance, Setho narrated "I know Excel and SPSS. I also know GeoGebra which have not use it before. I use SPSS and Matlab for my assessment and evaluation and not purposely for classroom instructions". This is an indication that after a decade of introducing technology as a medium of instruction in the national mathematics curriculum, teachers are yet to use it meaningfully to orchestrate mathematics lessons.

Table 2
Teachers' Perceived Technology Integration Knowledge in Mathematics Teaching

TPCK construct	Example	Mean(SD)
Technology knowledge (TK)	I know how to solve my own technical problems.	2.74 (0.53)
Technology content knowledge (TCK)	I can find and evaluate the resources that I need for my mathematics learning.	2.91 (91)
Technology pedagogy knowledge (TPK)	I can choose technologies that enhance the teaching approaches for a lesson	3.14 (0.80)
Technology pedagogy content knowledge (TPCK)	I can teach lessons that appropriately combine mathematics concept, technologies and teaching approaches.	3.06 (0.65)

Teachers' Views about Professional Development Model

The responses from the teachers indicated that the design team approach, expert support demonstration lessons, and exemplary materials adapted in this professional development model had a great impact in developing their technology integration knowledge, beliefs, and attitudes. The results in Table 3 indicate that teachers held strong view that working in design teams is time efficient (as they share roles among themselves), it helps them collaborate with others (they had ownership of the GeoGebra-based lessons they designed), and it provided them opportunity to learn (unique talents are tapped from each individual).

Table 3
Teachers' Perceived Benefits of Learning Technology by Design Team Approach

Components of design team	Mean(SD)
Appreciation about the collaboration	4.23 (.24)
Learning opportunities	4.61 (.38)
Development of technology integration knowledge	4.42 (.48)
Opportunity for collaboration	4.32 (.52)
Time efficiency	4.23 (.39)

Expert support was crucial during the lesson preparation stage by the teachers. A point in case is the lesson on trigonometric ratios designed by team three. The group initially struggled with how to insert a textbox that will animate and at the same time show the values of the trigonometric ratios as any of the vertices of the right-angled triangle is dragged. This challenge was resolved upon expert support and the teachers were able to develop and use the diagram in the GeoGebra window to gradually unfold the content of trigonometric ratios to students.

The demonstration lessons and teaching rehearsals afforded the teachers opportunity to put their perceived technological knowledge, pedagogical beliefs, and attitudes into practice. For example, Philo was able to use GeoGebra to scaffold student geometric learning and thinking. Using GeoGebra, Philo was able to build on student's previous ideas on the area of a circle to establish that the volume of a cylinder is $\pi r^2 h$ and that of the cone is a third of $\pi r^2 h$ (see Figure 1). Setho appropriated the GeoGebra tools: point, line segment, polygon, angle measure, slider, textbox, export graphics, and formatting to create a simulated object that helped students conceptualise the orientation of an object when it is rotated either clockwise or anticlockwise about the origin (see Figure 1). The teachers indicated using GeoGebra changes their instructional approach to a more student-centred approach where students co-operatively construct mathematics concepts.

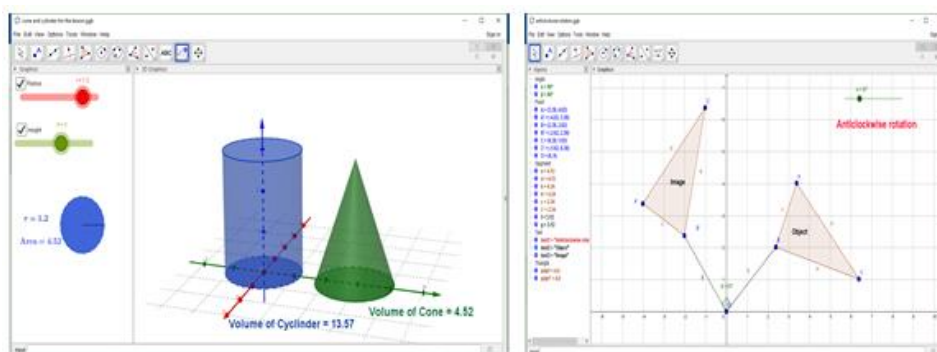


Figure 1. GeoGebra learning environment conducted by Philo and Seth.

It was observed that providing teachers the opportunity to work in the GeoGebra environment, influenced their confidence and willingness to use technology in the classroom. The teachers were observed to be eager learning how to integrate technology in mathematics. All the 11 in-service teachers, having experienced GeoGebra support lessons, admitted that teaching in such a technological environment was interesting and enhanced students' attention and participation. Thus, perceived pedagogical importance of a particular technology motivates teachers to apply it in their classroom decisions.

...we were motivated to design a lesson on circle theorem because that topic challenges students in examination. We saw GeoGebra as a powerful software which we can use to help students to understand the properties of circle theorem. (Patrick)

With regards to the exemplary materials, the teachers in the study acknowledged that the exemplary materials (GeoGebra tutorial, exemplary lesson plan, and GeoGebra online community) provided them with practical insights for preparing and enacting technology-based lessons. For example, the teachers indicated that the GeoGebra tutorial was helpful because it provided them the basis to learn the GeoGebra tools (geometric, constructing, and algebraic tools) which they applied in the lessons they developed. The exemplary lesson

plans stimulated teachers' reflection and further broadened their understanding of integrating technology into their classroom practices. The GeoGebra online community provided opportunity for teachers to adopt existing mathematics lessons for their classroom instructions. The teachers pointed out that to be proficient in the use of GeoGebra requires commitment and continuous practice.

Discussion and Conclusion

The purpose of this research study was twofold: first, it was to gain insights into teachers' initial dispositions related to the use of technology in mathematics teaching; second, it was to examine teachers' views about the professional development model where they worked in groups to develop and teach technology-based mathematics lessons.

With regards to teachers' disposition related to technology use, the results indicate that teachers have positive beliefs about the importance of technology in the classroom. The teachers have high intentions and willingness to employ technology into their pedagogy because they believe it can make students learn mathematics concepts meaningfully and independently. The teachers acknowledged the pedagogical importance of technology, yet admitted they had not been able to use it in the way they hoped because they had limited knowledge and skills to apply the technology in their classrooms. These findings support the results of earlier studies reporting on Ghanaian mathematics teachers' technology integration knowledge (Agyei & Voogt, 2012). Agyei and Voogt reported that Ghanaian mathematics teachers do not have the needed knowledge and skills to apply technology in mathematics. The results of our study elaborate the existing literature that teachers' competence of blending their technology knowledge with their existing pedagogical and content knowledge is critical in successful implementation of technologies in the classroom (Mishra & Koehler, 2006; Webb & Cox, 2004). Though teachers' values and beliefs about the importance of technology is necessary, their technology competence in terms of knowledge and skills seems to play a key role in technology integration.

With regards to the second purpose of this research study, the results indicate that teachers are very responsive to a technology integration programme that involves pedagogical activities. The teachers acknowledged that coming together as a team to design technology-based mathematics lessons had a remarkable influence on their TPACK development. The design teams are an essential approach for not only stimulating and supporting teachers to learn but it makes them active consumers of technological tools, initiates them to be designers of technology resources, and make them claim the local ownership of technology resources (Agyei & Voogt, 2012). It offered them the opportunity to share classroom experiences. Demonstration lessons adopted in the professional development model provided teachers the basis for replication and stimulated them to learn from their own practice. It was noted that the initial challenges teachers experienced when designing technology-based lesson were resolved upon expert support. This is an indication that the "provision of scaffold tasks to teachers and the opportunity to collaborate with experts and peers enhances teachers' learning" (Kafyulilo, Fisser, & Voogt, 2015, p.677).

It was noted in this study the introduction of GeoGebra offered the teachers the opportunity to put their technology integration knowledge as well as their personal and pedagogical beliefs, confidence, and willingness to use technology into practice. The teachers in the study reported that using technology changed their instructional approach to a more student-centred approach. Teachers were able to align their instructional objectives and activities for the learners to negotiate and construct their own mathematics concepts. It was observed that teachers used multiple situations created in GeoGebra to assist students'

conceptions of properties of circle theorem, solid geometry, and clockwise and anticlockwise rotation of an object about the origin. Also, it was observed that GeoGebra has the potential of accommodating individual teachers' busy schedules by adopting existing instructional lessons from the GeoGebra online community. The exemplary GeoGebra-based lessons developed and implemented by the first author initiated teachers' reflection and further broadened their understanding of subject matter for integrating technology into their classroom practices. In spite of the benefits of using GeoGebra, it requires commitment and continuous practice to be proficient in its use.

In summary, the results from this study provide strong evidence that teachers' may have high values and beliefs about technology importance, but they require technology knowledge and skills for effective implementation. The professional development model where teachers work in design teams to develop GeoGebra-based mathematics lesson with support from expert, lesson demonstrations, and exemplary materials offers an appropriate approach for teachers to be engaged in technology integration.

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