How do Teachers' Motivational Beliefs and Sense of Preparedness to Teach Mathematics Relate to their TPACK?

Adem Ekmekci
Rice University, USA
ekmekci@rice.edu

Mahtob Aqazade
Rice University, USA
ma119@rice.edu

Anne Papakonstantinou
Rice University, USA
apapa@rice.edu

Abstract: By providing a study on mathematics teachers' technological pedagogical content knowledge (TPACK), the goal of this study is to understand the impact of a professional development program on teachers' level of TPACK and to investigate the predictive value of teachers' beliefs (e.g., self-efficacy) and sense of preparedness to teach mathematics on their level of TPACK. We surveyed 225 K-12 in-service mathematics teachers who participated in a two-week professional development program during the years 2018–2022. Repeated-measures (pre-post) *t*-test was conducted to explore the change before and after professional development. Regression analysis was conducted to investigate the predictive value of aforementioned factors on the level of TPACK. The results indicate that professional development focusing on the mathematics content, pedagogy and integration of technology improves teachers' level of TPACK for all K-12 teachers. The other set of findings relate to the types of beliefs that predict the level of TPACK. At the elementary level, the most important factor associated with TPACK is the general teaching self-efficacy, whereas for high school teachers, it is the content specific teaching self-efficacy that strongly relates to TPACK. Pedagogical preparedness is also an important factor that is associated with TPACK.

Keywords: TPACK, Self-efficacy, Epistemic beliefs, Pedagogical preparedness, Mathematics teachers.

Introduction

This paper focuses on mathematics teachers' technological pedagogical content knowledge (TPACK) and factors affecting their TPACK. The issues that teachers face in their attempt to successfully integrate technology into the classroom are perhaps more nuanced than we usually think. When trying to integrate technology effectively into their daily instruction, teachers may face several internal/self-barriers such as how confident they feel about the subject matter and how prepared they feel to teach that content.

The discussion of beliefs in the context of TPACK may primarily be associated with beliefs about technology or technology use/integration itself, which would be a natural and straightforward association (see Abbitt, 2011, Corkin et al., 2016). However, the authors of this study take a different approach by investigating the link between beliefs related to other aspects of teaching including epistemic beliefs about the content and self-efficacy in general and in content-specific teaching. TPACK provides a framework that is at the nexus of all content, pedagogy, and technology (Schmidt et al., 2009). Narrowing beliefs and practice to only technology-related aspects would be an inadequate examination within the TPACK framework. Since research indicates teachers' beliefs, content knowledge, and practices are interwoven (Corkin et al., 2016; Schoenfeld, 2016), it is conceivable and likely that TPACK is also related to or even affected by teachers' beliefs and practices in the content area (Rosenberg & Koehler, 2015). For instance, it is possible that self-efficacy in one's teaching of a subject or in the subject matter itself may also relate to TPACK. This concern raises some relevant and important questions regarding the relationship between beliefs and TPACK. For example, how do teachers' self-efficacy beliefs about mathematics influence their TPACK? Could a teacher who has availing epistemic beliefs about mathematics (i.e., seeing it as a more dynamic rather than as a static discipline) have a higher level of TPACK? Could a teacher who has higher levels of confidence and interest in teaching mathematics have more flexibility in technology integration into mathematics instruction?

To shed light on these relevant questions, this paper will contribute to the body of research and practice in several ways. First, the results are expected to inform pre-service and in-service teacher professional development leaders about opportunities or ways to transform and enhance professional development programs by identifying secondary factors (Kim et al., 2013). For example, would epistemic beliefs make a difference in supporting teachers' TPACK development? Second, this study will complement the widely-used different TPACK frameworks, as they, in their current proposed and used forms, do not address "beliefs" about different aspects of teaching to the extent that they should (Ekmekci et al., 2019).

The following research questions guided this study:

1. To what extent did teachers' level of TPACK change during the two-week summer professional development program?
2. To what extent did teachers' educational beliefs (teaching self-efficacy, self-concept in mathematics, epistemic beliefs in mathematics, and sense of preparedness to teach mathematics) predict TPACK at the completion of the two-week professional development program?

Background

Shulman (1986) proposed that teachers' content knowledge base consists of subject-matter content knowledge, pedagogical content knowledge (PCK), and curricular knowledge. Though, more often than not, content knowledge refers to subject-matter content knowledge. He referred to subject-matter as "the amount and organization per se in the mind of the teacher" (Shulman, 1986, p. 9). Since Shulman, many researchers have dissected or modified his base concepts. For example, in contrast to Shulman's model, various researchers have incorporated ideas into PCK that were regarded as part of distinct knowledge bases. In addition to content and pedagogy, various researchers have highlighted other knowledge bases like curriculum, context, student perception and purpose (e.g., Ball et al., 2008; Niess et al., 2019).

Recent research is focused on topic specific PCK. Ball et al. (2008) have constructed a framework to represent mathematical knowledge for teaching (MKT). "Probably the most influential reconceptualization of teachers' PCK within mathematics education was done through the overarching construct of MKT" (Depaepe et al., 2013, p. 13). The following concepts compose MKT: common content knowledge, specialized content knowledge, knowledge of content and students, and knowledge of content and teaching. On acquiring these types of knowledge, the teacher must (1) be able to do the work assigned to students, (2) possess knowledge beyond the curriculum, (3) predict what students are going to think, and what they will find confusing, and (4) organize the content for instruction. To clarify the connection between MKT and TPACK, it is fair to say that MKT basically covers both content knowledge and PCK, two important dimensions of TPACK (Depaepe et al., 2013); however, it misses the third component, technology.

Since the advent of accessible technology, many scholars have realized the necessity to include technology as part of the existing PCK (Angeli & Valanides, 2009; Mishra & Koehler, 2006; Niess et al., 2019). Teachers must know not only how to use technology but also how to include technology as a pedagogical tool and how to select the most apt technology for conveying subject matter. Having technical expertise would not imply better use of technology in teaching, and hence, generic technological training would not help (Mishra & Koehler, 2006). Today, researchers and teacher educators unanimously agree upon the importance of integrating technology into teacher preparation programs with expected outcomes such as effective utilization of technology for teaching particular topics, knowledge of students' understandings, thinking and learning with technology in a particular subject (Kartal & Çınar, 2022; Zambak & Tyminski, 2020), and knowledge of curriculum materials that integrate technology with learning in the subject area.

The TPACK construct has been defined in several ways. Niess (2005) perceived TPACK as an extension of PCK. Mishra and Koehler (2006) described it as the intersection among technology, pedagogy, and content, basing it on the same principles as Shulman with the addition of the technological component. Angeli and Valanides (2009) put forward the concept of information and communication technology, a component under the TPACK umbrella which focused on the integrating of modern-day digital technologies into teaching. It is constituted by the following knowledge bases: subject matter knowledge, pedagogical knowledge, technology, knowledge of students and knowledge of context within which learning takes place. As a distinct form of knowledge, TPACK has been considered as complex, multi-faceted, integrative, and/or transformative (Angeli & Valanides, 2009; Mishra & Koehler, 2006). Cox and Graham (2009) defined TPACK as "a teacher's knowledge of how to coordinate the use of subject-specific activities or topic-specific activities with topic-specific representations using emerging technologies to facilitate student learning" (p. 64).

Research on teachers' beliefs and knowledge

Teacher characteristics including soft attributes such as beliefs and attitudes are considered an important part of teacher quality (Ekmekci & Serrano, 2022; National Council on Teacher Quality, 2004; Schoenfled, 2016) and should not be disregarded when examining a prominent construct such as TPACK (Angeli & Valanides, 2009; Rosenberg & Koehler, 2015). Research indicates that teachers' domain-specific knowledge for teaching and their educational beliefs about teaching have strong connections to their knowledge development, decision-making, planning, and instructional practices (Hill et al., 2012).

The educational beliefs that may be relevant to mathematics teaching effectiveness are teachers' beliefs about their ability to effectively perform mathematics teaching-related tasks (self-efficacy; Enochs et al., 2000) and teachers' beliefs about the nature of mathematics knowledge (epistemic beliefs; Hofer, 2000). Within the teaching domain, teachers' self-efficacy may be defined as the extent to which teachers believe they can successfully execute teaching-related tasks within a particular context (Tschannen-Moran & Hoy, 2007). Perceived self-efficacy within a given domain has been found to predict performance within that domain beyond observed ability (Chai et al., 2013). Previous studies have found that mathematics teachers who are less self-efficacious are more likely to ascribe to traditional mathematics classroom practices compared to their more self-efficacious peers (e.g., Stipek et al., 2001).

Epistemic beliefs can be defined as an individual's beliefs about knowledge, which includes one's beliefs about where knowledge comes from, what the essence of knowledge is, and how one comes to know and justify beliefs. Educational psychology research has conceptualized and measured epistemic beliefs as residing across two ends of a spectrum: (a) non-availing—knowledge is fixed, simple, certain, objective, and comes from a person of authority; and (b) availing—knowledge is evolving, complex, uncertain, subjective, and stemming from a person's own construction of knowledge (Muis & Duffy, 2013). Availing epistemic beliefs are associated with positive motivational processes and academic achievement and have been shown to influence instructional approaches (Schoenfeld, 2016). Moreover, instructional practices as well as decision-making and planning have been shown to be strongly related to knowledge and beliefs (Hill et al., 2012). For instance, teachers' effective standards-based mathematics teaching and pedagogical activities are often driven by teachers' educational beliefs including self-efficacy and pedagogical content knowledge (Corkin et al., 2015).

Research also indicates that intrapersonal factors such as self-efficacy, outcome expectations, and interest interact with teacher motivation to integrate technology, and in turn, influence teachers' TPACK (Stewart et al., 2013). Despite its recognition as an important aspect of TPACK, contextual factors are often missing from TPACK (Rosenberg & Koehler, 2015).

Methods

Procedure

In this study, we surveyed K-12 in-service mathematics teachers who participated in a two-week professional development program aimed at improving teachers' pedagogical content and pedagogical knowledge. The five cohorts of teachers who were included in this study participated in the professional development program in one of five summers: 2018–2022. These two-week programs, Summer Campus Programs (SCP), consisted of 56 contact hours (2 weeks, 4 days a week, and 7 hours a day) and aimed to provide a rigorous mathematics instruction program for K-12 teachers, who attended one of three classes based on the grade level of their teaching assignments for the subsequent academic year. These classes were elementary (K-5), middle school (6-8), and high school (9-12).

Participating teachers took a pre-survey two to three weeks prior to each SCP and a post-survey the last day of the SCPs. The survey items assessed teachers' self-efficacy in teaching (in general) and in teaching mathematics (specifically), self-concept in math (i.e., confidence in doing math), pedagogical preparedness to teach mathematics, and level of TPACK.

First, we compared the results of post-survey with that of the pre-survey to explore the change in beliefs. Then, we investigated the predictive value of self-efficacy, self-concept, and sense of preparedness on the level of TPACK.

Participants and data collection

Representing several urban school districts in the southwestern U.S., 225 K-12 mathematics teachers participated in the study. The majority of these teachers (more than 90%) were teaching in high poverty schools. In terms of gender, 74% were females. The ethnic make-up of the sample consisted of 42% White, 13% African American, 32% Hispanic, 10% Asian, and 3% other. Teachers, on average, had seven years of mathematics teaching experience. The grade-level breakdown was as follows: 99 teachers taught elementary (grades K-5), 78 taught middle school (grades 6-8), and 44 taught high school (grades 9-12).

Measures

The survey consisted of a battery of scales measuring different constructs. These scales were adapted from previously developed and validated instruments, and they are as follows: math self-concept (six items; Marsh,1990), epistemic beliefs (eight items; Hofer, 2000), teaching self-efficacy in general (4 items; Klassen et al., 2009), math teaching self-efficacy (13 items; Enochs et al., 2000); pedagogical preparedness (13 items; Germuth et al., 2003), and TPACK (11 items; Schmidt et al., 2009). Epistemic beliefs, math teaching self-efficacy, and TPACK items were on a 5-point Likert scale (1-strongly agree to 5-strongly agree). The stem for the items was the extent to which teachers agreed with the given statements. Items included "*Truth is unchanging in mathematics*" (epistemic beliefs); "*I'm continually finding better ways to teach mathematics*" (math teaching self-efficacy; and "*I can teach lessons that appropriately combine mathematics, technologies, and teaching approaches*" (TPACK).

Math self-concept items were also on a 5-point Likert-scale (1-not like me at all to 5-very much like me) An example is "*Compared to my colleagues, I am good at mathematics.*" General teaching self-efficacy items were also on a 5-point Likert-scale (1-nothing to 5- a great deal). An example is "*How much can you do to implement a variety of assessment strategies?*" Lastly, pedagogical preparedness-items were on a 4-point Likert-scale (1-not adequately prepared to 4-very well) as a response to question stem about how prepared they felt for tasks such as "*taking students' prior understanding into account when planning curriculum and instruction*."

Results

In this paper, we investigated the extent of the change in teachers' level of TPACK from the onset of a two-week summer professional development program to the post- professional development program. In addition, we investigated the extent of the predictive value of teachers' beliefs on their level of TPACK.

School level	***t* value**	**df**	***p* value (2-tailed)**	**Mean difference (post-pre)**	**Standard error (difference)**	**95% Confidence Interval of the Difference**	
						Lower	**Upper**
Elementary School	6.19	89	< 0.001	0.44	0.07	0.30	0.58
Middle School	3.58	60	< 0.001	0.25	0.07	0.11	0.38
High School	1.51	35	< 0.05	0.19	0.10	-0.02	0.40

Table 1. Summary of Independent Samples *t*-Test for TPACK.

Table 1 presents the results for the change in TPACK level from pre- to post- professional development as analyzed by the repeated measures (paired samples) *t*-tests. The results are broken down by the school level (i.e., summer professional development class level) to allow for more meaningful interpretations at the elementary, middle, and high-school level. Even though the SCP seems to have improved teachers' level of TPACK at all school levels, this positive impact seems to be at a more significant level for elementary and middle school teachers ($p < 0.001$).

Variables	**Coeff.**	**S.D**
Intercept	.85	.44
Math self-concept	.01	.05
Epistemic beliefs	.04	.07
Teaching self-efficacy	.18*	.08
Math teaching self-efficacy	.29**	.09
Pedagogical preparedness	.29***	.08

Notes. Outcome is TPACK level. *$p < .05$. **$p < .01$. ***$p < .001$

Table 2. Summary of Regression Analyses Predicting Teachers' TPACK Level—All Teachers.

Table 2 presents the regression results for predicting teachers' level of TPACK for all teachers combined. Teaching self-efficacy, mathematics teaching-self-efficacy, and pedagogical preparedness were significant predictors of TPACK.

Variables	***Elementary School***		***Middle School***		***High School***	
	Coeff.	**S.D**	**Coeff.**	**S.D**	**Coeff.**	**S.D.**
Intercept	0.64	0.82	0.74	0.62	0.64	0.76
Math self-concept	-0.06	0.08	0.05	0.10	-0.17	0.15
Epistemic beliefs	0.00	0.11	0.04	0.11	0.06	0.15
Teaching self-efficacy	0.34*	0.15	0.23	0.13	-0.02	0.15
Math teaching self-efficacy	0.34	0.20	0.12	0.14	0.58**	0.16
Pedagogical preparedness	0.18	0.15	0.38**	0.13	0.44**	0.15

Notes. Outcome is TPACK level. *$p < .05$. **$p < .01$

Table 3. Summary of Regression Analyses Predicting Teachers' TPACK Level by School Level.

Table 3 presents the regression results broken down by school level. At the elementary school level, teachers' general teaching self-efficacy is found to significantly influence their level of TPACK. For middle school mathematics teachers, pedagogical preparedness significantly predicted their level of TPACK. Finally, for high school mathematics teachers, self-efficacy in teaching mathematics and pedagogical preparedness were significant predictors of level of TPACK.

Discussion and Conclusions

Several aspects of teaching that were deemed important but not researched to a sufficient extent in the literature have been explored in this study to understand their relation to TPACK. These aspects included mathematics self-concept, epistemic beliefs in mathematics, teaching self-efficacy (both general and mathematics-specific), and pedagogical preparedness.

The results indicate that professional development focusing on mathematics content, pedagogy and integration of technology improves teachers' level of TPACK for all K-12 teachers. Even though instructors of the classes for teachers (across elementary, middle, and high school classes) and the content focus across years were different, this finding is very promising in that content-technology, and pedagogy-focused professional development improve teachers' TPACK.

The other set of findings relates to the types of beliefs that predict the level of TPACK. Teaching self-efficacy, mathematics teaching-self-efficacy, and pedagogical preparedness were significant predictors of TPACK. When broken down by school level, the most important factor associated with TPACK at the elementary level is the general teaching self-efficacy, whereas for high school teachers, it is the content specific teaching self-efficacy that strongly relates to TPACK. Pedagogical preparedness is also an important factor that is associated with TPACK for middle and high school teachers. This may also imply that the higher the level of TPACK, the more prepared teachers feel to teach mathematics at the middle and high school levels. Therefore, it is important that professional development programs for teachers focus on developing teachers' TPACK rather than just focusing on one component of this construct (i.e., only content or only pedagogy). On the other hand, the direct focus on all components may not always be possible or feasible. In that case, focusing on self-efficacy and pedagogical preparedness based on teachers' needs can also be effective at improving teachers' TPACK, as the findings indicate in this study.

Interpreting these results under the premise that teachers' beliefs, knowledge, and practices are all intertwined, improving teachers' beliefs and TPACK can return great benefits for the mathematics education community. Expanding on this premise, what teachers believe might influence what they learn, and what they learn might change what they do in their instruction (Ball, 1996; Stipek et al., 2001). Of course, what follows (or should follow) these changes in teachers are student outcomes. Therefore, future studies may focus on investigating the association between teachers TPACK and student outcomes.

References

Abbitt, J. T. (2011). An investigation of the relationship between self-efficacy beliefs about technology integration and technological pedagogical content knowledge (TPACK) among preservice teachers. *Journal of Digital Learning in Teacher Education*, *27*(4), 134–143.

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, *52*(1), 154–168.

Ball, D. L. (1996). Teacher learning and the mathematics reforms: What we think we know and what we need to learn. *Phi Delta Kappan*, *77*(7), 500–508.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407.

Chai, C. S., Koh, J. H. L., & Tsai, C. C. (2013). A review of technological pedagogical content knowledge. *Journal of Educational Technology & Society*, *16*(2), 31–51.

Corkin, D., Ekmekci, A., & Papakonstantinou, A. (2015). Antecedents of teachers' educational beliefs about mathematics and mathematical knowledge for teaching among in-service teachers in high poverty urban schools. *Australian Journal of Teacher Education, 40(*9), 31–62.

Corkin, D., Ekmekci, A., White, C., & Fisher, A. (2016). Teachers' self-efficacy and knowledge for the integration of technology in mathematics instruction at urban schools. In K. V. Adolphson & T. M. Olson (Eds.), *Proceedings of the 43rd Annual Meeting of RCML,* (pp. 101–108). Orlando, FL.

Cox, S., & Graham, C. R. (2009). Diagramming TPACK in practice: Using an elaborated model of the TPACK framework to analyze and depict teacher knowledge. *TechTrends: Linking Research & Practice to Improve Learning*, *53*(5), 60–69.

Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education*, *34*, 12–25.

Ekmekci, A., Papakonstantinou, A., Parr, R., & Shah, M. (2019). Knowledge, beliefs, and perceptions about the mathematics and mathematics teaching: How do they relate to teachers' technological pedagogical content knowledge? In M. L. Niess, H. Gillow-Wiles, & C. Angeli (Eds.), *Handbook of research on TPACK in the digital age,* (pp. 1–23). Hershey, PA: IGI Global. DOI: 10.4018/978-1-5225-7001-1

Ekmekci, A., & Serrano, D. M. (2022). The impact of teacher quality on student motivation, achievement, and persistence in science and mathematics. *Education Sciences*, *12*(10):649, 1–21. DOI: 10.3390/educsci12100649

Enochs, L. G., Smith, P. L., & Huinker, D. (2000). Establishing factorial validity of the mathematics teaching efficacy beliefs instrument. *School Science and Mathematics, 100*(4), 194–202.

Germuth, A., Banilower, E., & Shimkus, E. (2003). *Test-retest reliability of the Local Systemic Change teacher questionnaire*. Chapel Hill, NC: Horizon.

Hill, H. C., Umland, K., Litke, E., & Kapitula, L. R. (2012). Teacher quality and quality teaching: Examining the relationship of a teacher assessment to practice. *American Journal of Education*, *118*(4), 489–519.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*(4), 378–405.

Kartal, B., & Çınar, C. (2022). Preservice mathematics teachers' TPACK development when they are teaching polygons with geogebra. *International Journal of Mathematical Education in Science and Technology*, 1–33. https://doi.org/10.1080/0020739X.2022.2052197

Kim, C., Kim, M. K., Lee, C., Spector, J. M., & DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education*, *29*, 76–85.

Klassen, R. M., Bong, M., Usher, E. L., Chong, W. H., Huan, V., Wong, I. Y., & Georgiou, T. (2009). Exploring the validity of a teachers' self-efficacy scales in five countries. *Contemporary Educational Psychology, 34*, 67–76.

Marsh, H. W. (1990). The structure of academic self-concept: The Marsh/Shavelson model. *Journal of Educational Psychology*, *82*(4), 623–636.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054.

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology, 105*(1), 213–225.

National Council on Teacher Quality (2004). *Increasing the odds: How good policies can yield better teachers.* Author. Available at https://www.nctq.org/publications/home

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, *21*(5), 509–523.

Niess, M. L., Gillow-Wiles, H., & Angeli, C. (Eds.). (2018). *Handbook of Research on TPACK in the Digital Age*. IGI Global.

Rosenberg, J. M., & Koehler, M. J. (2015). Context and technological pedagogical content knowledge (TPACK): A systematic review. *Journal of Research on Technology in Education*, *47*(3), 186–210.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education, 42*(2), 123–149.

Schoenfeld, A. H. (2016). Research in mathematics education. *Review of Research in Education*, *40*(1), 497–528.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Stewart, J., Antonenko, P. D., Robinson, J. S., & Mwavita, M. (2013). Intrapersonal factors affecting technological pedagogical content knowledge of agricultural education teachers. *Journal of Agricultural Education*, *54*(3), 157–170.

Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education*, *17*(2), 213–226.

Tschannen-Moran, M., & Hoy, A. W. (2007). The differential antecedents of self-efficacy beliefs of novice and experienced teachers. *Teaching and Teacher Education*, *23*(6), 944–956.

Zambak, V. S., & Tyminski, A. M. (2020). Examining mathematical technological knowledge of pre-service middle grades teachers with Geometer's Sketchpad in a geometry course. *International Journal of Mathematical Education in Science and Technology*, *51*(2), 183–207. https://doi.org/10.1080/0020739X.2019.1650302