Teacher Cooperation and Education Levels as Contributors of Teachers' ICT Use

Elisheba Kiru

African Population Health and Research Center, Kenya

Abstract

Globally, there is considerable investment in education technologies leading to increased attention from stakeholders (Trucano, 2017). For a deeper understanding about the implementation of various technologies, research is needed to examine how teachers are incorporating them in teaching and learning. This study focused on eight countries to examine how teachers used ICT in mathematics instruction and factors that contributed to ICT use. Results show that teachers' education levels and cooperation amongst educators are associated with ICT use in instruction. The paper includes recommendations and implications for practice and future research.

Keywords: *teachers, ICT, mathematics, socio-cultural theory, K-12*

Author Note

Elisheba Kiru 0000-0003-3187-5996
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Correspondence concerning this article should be addressed to: Elisheba Kiru, African Population Health and Research Center, Kenya. Email: ekiru@aphrc.org.

Teacher Cooperation and Education Levels as Contributors of Teachers' ICT Use

Technology advancements continue to alter and disrupt the traditional ways of communicating, ways of engaging in commerce, and ways of sharing knowledge in our world. Information and communication technologies (ICT) refers to electronic devices (e.g., laptops, Chromebooks), handheld devices (e.g., iPads, iPods), interactive devices (e.g., interactive white boards), application software, and social media platforms (e.g., Twitter, Facebook). ICTs have become integral in daily living. With increased ubiquity coupled with increased attention from stakeholders, countries around the world continue to invest heavily in ICT for education despite inconclusive findings on the effectiveness on learning (De Witte & Rogge, 2014; Trucano, 2017). However, it is often assumed that the mere presence of ICT in the classroom will lead to changes in instructional practices and enhance student learning in core subjects such as mathematics. In the United States, although schools and classrooms have also experienced a proliferation of ICT, teaching practices using ICT remain largely unchanged (Bain & Weston, 2012; Cuban, 2001, 2013; Peck et al., 2015). Scholars report that instructional practices with ICT remain teacher-centered with little attention towards the development of teaching and learning opportunities that promote creativity and high-order thinking (Hughes & Read, 2018). Relatedly, education reforms have an increased focus on emphasizing educational experiences that provide learners with opportunities for creativity, collaboration, and the development of critical thinking.

Therefore, it is safe to say that this proliferation of ICT has not occurred in a vacuum. The increase in ICT in classrooms exists in an educational landscape characterized by education reform movements, high stakes testing, and teacher accountability, all efforts deemed to improve teacher quality, increase student achievement, and prepare students for the 21st century. Arguably, these shifts in the educational landscape are a product of the involvement of global players such as the Organization for Economic Cooperation and Development (OECD), the World Bank, and the global technology industry in influencing educational policy developments around the world and subsequently contributing to the remaking of classrooms (Akiba, 2017; Fullan, 2015; Pont, 2018). One major shift was the introduction of mobile technology in 2007, which changed the understanding of ICT and its utility. Some of these shifts require educators to prepare students for a knowledge-based economy in an increasingly connected global environment (Darling-Hammond, 2010; Friedman, 2005; OECD, 2012). Additionally, the results of international student performance assessments (e.g., Programme for International Student Achievement [PISA]) have increased the expectations of education systems and resulted in calls for schools to innovate (Altrichter & Posch, 2009; Lingard et al., 2013). Following the massive school closures brought by COVID-19, many countries resorted to incorporating ICT as a solution to the unprecedented disruptions in teaching and learning. Although distance-learning approaches have been heralded as alternatives to regular online learning, Selwyn (2021) posits that these digital responses for learner continuity should be more aptly understood as "emergency remote schooling" (p. 3). Scholars (e.g., Hodges et al., 2020) have echoed this sentiment and defined the teaching during the COVID-19 pandemic as emergency remote teaching that served as a response to a crisis.

Investing in technology for teaching and learning is seen as a catalyst to spark innovation and prepare global learners (McKnight et al., 2016). However, there is a need for a focus beyond access to ICT to an examination of how teachers use ICT in instruction as well as teachers' views about ICT and learning (Ditzler et al., 2016). Research on how teachers use ICT in teaching and learning is growing but is still limited compared to research on different educational aspects (McKnight et al., 2016, Schuetz et al., 2018; Willis et al., 2019). Additionally, emerging evidence shows that research focused on technology integration covers a broad variety of types of technologies, in different contexts, for different purposes (Bray & Tangney, 2017). Therefore it is important to understand that learning technologies exist in different environments and for different purposes.

Examining the school context (school context refers to the environment where teaching and learning takes place) and the different relationships among key stakeholders (e.g., teachers, students, school leaders) in a learning environment can reveal assumptions about ICT and provide insights into ICT integration (Fullan, 2015). These relationships can explain the factors that contribute to the varied ways that teachers use ICT in instruction, challenges in effectively integrating ICT, and the impact that ICT-enhanced instruction has on both student academic and non-academic outcomes. Most importantly**,** it is imperative for stakeholders (e.g., researchers, policy makers, school leaders) to collaborate with curriculum developers and teachers in aligning curriculum with ICT goals to design a coherent vision of the role of ICT in classrooms for the benefit of student learning.

Students need mathematics skills in various settings beyond the classroom to be successful (Clarke et al., 2014). In the United States, low rankings in mathematical performance have fueled educational reform practices to better equip students with the necessary skills for a competitive global market (Turgut, 2013). Low student mathematics performance in the U.S. persists despite increased spending in K-12 education (McFarland et al., 2017). For instance, the PISA is an international assessment administered every three years to assess the reading, mathematics, or science skills of 15-year-olds in participating OECD countries, and PISA results from the 2018 examinations show that in the United States, students struggle with understanding real-life mathematics scenarios and developing mathematical models when solving mathematical problems (OECD, 2019). Researchers have posited that technology has affordances that can improve mathematics instruction (Bray & Tangney, 2017). ICT can be used in mathematics instruction to provide students with real-life examples and opportunities to develop modeling skills, promote students' understanding of abstract mathematical concepts, make conjectures, and develop high-order skills. Scholars argue that technology can foster student engagement in mathematics (Evans et al., 2015; Haydon et al., 2012). However, it is unclear whether teachers make these higher-order learning opportunities available to students, especially using ICT across content areas (Hennessy et al., 2005; Howard et al., 2015).

To this end, the purpose of this study is to embrace a global outlook in understanding education trends, with a special focus on teachers' ICT use in mathematics instruction. The study accomplishes this objective by using data from the Teaching and Learning International Survey (TALIS) (OECD, 2013). In 2013, the TALIS survey was the first international series of surveys with a major focus on the learning environment and working conditions of teachers in schools. The survey examined pedagogical and professional practices of teachers as well as how school-level policies and practices shaped the working and learning environment. In this study, ICT use is defined as how teachers incorporate ICT in mathematics instruction. The mathematics questionnaire had a question on ways that teachers use ICT. These included use of topic-specific software, drills and practice, spreadsheets, the internet, and assessments.

Background

International Trends in ICT

Countries around the world have invested heavily in ICT for education, and this has led to increased attention from stakeholders compared to a decade ago when discussions on ICT were very limited (Trucano & Dykes, 2017). Arguably, the dynamic nature of ICT offers affordances previously absent from the learning environment and provides teachers and learners with tools that can enhance creativity, collaboration, and critical thinking. As technology costs have decreased, proliferation of ICT in classrooms has taken different forms (e.g., 1:1 initiatives) where schools provide each student with a device (e.g., laptop, Chromebook) or schools ask students to bring their own devices. With increased connectivity and the ubiquitous nature of ICT, learning is taking place beyond traditional parameters (e.g., classroom walls, regular school day) and across geographical locations. However, even with increased connectivity, a digital divide exists within countries either between urban and rural areas and/or between high and low-income schools (Chen, 2015).

Proliferation of ICT has also brought to the fore discussions about pedagogical innovations and effects on learning outcomes. With ICT affordances such as personalized learning, immediate feedback, and data-based decision making, it is argued that teaching approaches will become more student-centered and less teacher-centered (El Yacoubi, 2013). However, the overall effectiveness of ICT on learning outcomes remains mixed with the reality of teachers underutilizing ICT in meaningful and enriching ways. Overall, the dynamic nature of ICT continues to change educational experiences for students in places around the world. However, success in ICT hinges on a number of factors, such as effective leadership and systemic changes in the organizational structures (i.e., schools and classrooms) (Trucano & Dykes, 2017). Effective leadership involves the development of a shared vision on ICT in instruction, identification of the right contextual drivers, and an understanding of the role of *aligned curriculum*, *teacher training*, and *shared vision* (Fullan, 2015). An elaborate discussion on these factors is beyond the scope of this manuscript.

ICT and Mathematics

Students need mathematics skills in various settings beyond the classroom to be successful (Clarke et al., 2014). In the United States, low rankings in mathematical performance have fueled educational reform practices to better equip students with the necessary skills for a competitive global market (Turgut, 2013). With limited evidence on the effects of spending more on a student's education, low student mathematics performance persists despite increased spending in K-12 education (Guglielmi & Brekke, 2017). In 2015, the U.S. ranked 38th on the PISA (OECD, 2012). The PISA 2012 results show that in the United States, students struggle with understanding real-life mathematics scenarios and developing mathematical models when solving mathematical problems (OECD, 2012).

ICT affordances provide teachers and students with tools that can allow for multiple engaging ways of learning mathematics. ICT can provide students with real-life examples, opportunities to develop conjectures, modeling skills through simulation, graphing software, and connections with experts in different fields (Webb & Cox, 2004). In addition, coupled with effective pedagogy (Willis et al., 2019), teachers can use ICT in mathematics instruction to promote students' understanding of mathematical skills and concepts, make conjectures, and develop high-order skills. However, it is unclear whether teachers make these higher-order learning opportunities available to students, especially using ICT. Despite this mismatch of required skills, ICT proliferation in the classrooms, and lackluster learning opportunities, available literature addresses ICT use and student achievement with little attention to teachers' ICT use across content areas (Hennessy et al., 2005; Howard et al., 2015). The ICT affordances provide teachers and students with tools that can allow for different ways of investigating, developing, and learning mathematics. Research shows mixed results of ICT on K-12 students' mathematics engagement or achievement depending on the grade level and the targeted objectives (Willis et al., 2018). For instance, Schuetz et al. (2018) found that second-grade students in mathematics instruction (addition, subtraction, and word problems) who used technology and students who used paper/pencil were equally engaged. Scholars (e.g., Hilton, 2018; Ke, 2008; Musti-Rao & Plati, 2015; Ok & Bryant, 2016) found that students in grades three to five showed a significant positive effect on student engagement from teaching with technology. Similarly, researchers found that student engagement, time on task, and attitudes increased from technology-based instruction (Glassett & Schrum, 2009; Li & Pow, 2011; McClanahan et al., 2012; McKenna, 2012; Ok & Bryant, 2016; Rosen & Beck-Hill, 2012).

Teacher Training

Although examining student ICT use is critical, developing an understanding about how teachers use ICT in mathematics instruction can inform researchers, teacher educators, and policy makers on the existing gaps between ICT use in instruction, and the impact of ICT use on students' learning. Understanding how teachers use ICT in mathematics instruction can provide a clearer picture on aspects and affordances from ICT that improve mathematics learning.

Specifically, understanding teachers' pedagogical beliefs about ICT integration is paramount in comprehending the various ways teachers incorporate ICT in instruction (Ertmer, 2005). Furthermore, understanding the different mathematical tasks incorporated in ICT use can shed light on areas that need continued research, such as examining mathematical concepts where teachers use ICT, and examining the variation of tasks incorporated with ICT in instruction. It is also important to investigate the various factors (e.g., teacher beliefs about teaching and learning of mathematics or beliefs about ICT in teaching and learning mathematics) that may influence ICT use (Niess et al., 2009).

There is growing and converging research examining how teachers use ICT in mathematics instruction and whether mathematics teachers needed professional development in ICT to integrate ICT in teaching mathematics effectively (Wilson et al., 2020). An international analysis on how mathematics teachers use ICT and factors that contribute to ICT use in mathematics instruction can provide a broader perspective based on global contexts. Peripheral and differential ICT use is a well-documented phenomenon. As researchers and scholars seek to understand factors that contribute to these differences in the ways teachers incorporate ICT in instruction, teacher training is an area of need. With the plethora of ICT in the classroom and the expectation to use ICT in instruction, coupled with emergencies such as the COVID-19 pandemic, teachers have highlighted the need for more training on how to teach using ICT. The next section provides an overview of professional development and organizational culture as active ingredients that influence teachers' ICT use.

Active Ingredients in ICT Integration

Literature on ICT integration describes a variety of drivers critical for ICT integration. The drivers focus on access, quality, and the teaching and learning environment. Access can refer to hardware, software, or applications. Quality can refer to pedagogy. Context can refer to the entire classroom climate, school climate, or a country's ICT policies. Describing all these drivers is beyond the scope of this paper. To that end, this paper focuses on teacher cooperation and school contexts and therefore highlights teacher professional development and organizational culture as active ingredients of ICT integration.

Professional Development

Pedagogical practices include the ways teachers provide instruction and teachers' beliefs and values that influence their practices (Hardman, 2019). Professional development training for teachers focusing on social and organizational aspects of ICT integration is imperative for successful ICT integration (Zhao et al., 2002). Zhao et al. (2002) further argued that certain conditions such as teachers' awareness of available resources and compatibility of the ICT to existing instructional and school practices are needed for successful ICT integration. For instance, teachers with an understanding of the social culture in a school are more likely to negotiate some of the barriers that get in the way of ICT integration. These teachers may negotiate the barriers through collaborating with multiple parties in the school either to gain access to ICT resources or to garner peer support. In addition, there is a need for careful consideration of curriculum, pedagogy, professional development, teacher beliefs, teacher training, and school leadership, and their impact on teachers' ICT use (Ertmer & Ottenbreit-Leftwich, 2010; Frank et al., 2011; Hughes, 2005; Wilson et al., 2020). Wilson et al. (2020) conducted a meta-analysis on the effects of teacher education courses for technology integration (TECTI) on preservice teacher knowledge and found that knowledge about technology has a positive effect on teachers' technology integration. However, the type of knowledge that contributes to increased technology integration is unclear.

Organizational Culture

A school's organizational culture includes availability of technical assistance along with the administrative and peer support that allows ICT integration. The organizational culture cannot be underestimated because various stakeholders (e.g., teachers, school leaders) may have different assumptions about ICT, attitudes towards using ICT in teaching, student learning, or the role of the teacher in an ICT-rich environment (Somekh, 2007; Zhao et al., 2002). In addition, an organization's culture can explain the factors that contribute to the varied ways teachers use ICT in instruction and the impact that ICT-enhanced instruction has on both the academic and non-academic outcomes of students (e.g., motivation, engagement) (McKnight et al., 2016; Mouza, 2008; Overbay et al., 2010; Subramaniam, 2007).

To build robust organizational cultures, scholars have argued that there is a need to build capacity and collaborative cultures in schools (Fullan, 2015). Building capacity involves building skills and opportunities that foster the development of new experiences and increase motivation for teachers and school leaders to engage in change processes. Building capacity includes providing professional development for teachers and creating discussion spaces for stakeholders that facilitate development of effective and efficient ways to use available resources (e.g., ICT, teacher skills). Fullan also posits that there is a need for "connected autonomy," which fosters collaboration among teachers and allows for individual self-assessment as well as connections with larger educational goals (2015, p. 262). These social and organizational aspects impact ICT integration.

Theoretical Framework

The next sections describe two theoretical frameworks that guide the study. They include sociocultural theory and the Technological, Pedagogical, Content Knowledge (TPACK) framework. Sociocultural theory highlights the role of the sociocultural context in understanding teachers' ICT use and the TPACK framework exists in that sociocultural context and informs teachers' ICT use.

Sociocultural Theory

Sociocultural theory argues that learning is socially and culturally located in daily activities where an individual's behavior is influenced by the interaction of other individuals (Lave & Wenger, 1991; Moll, 1990; Rogoff, 1990; Somekh, 2007; Vygotsky, 1978). Understanding the social system and the relationships (e.g., institutional, historical, or cultural) that exist in a given system is necessary for understanding the uptake of ICT innovations in education (Borko, 2004; Somekh, 2007). The mini-contexts of classrooms exist in larger contexts of schools, and larger contexts within states and within countries. These larger contexts directly and indirectly influence classroom practices. Educational policies on ICT, teacher training on ICT use, or perceptions of ICT in teaching and learning intersect to impact instructional practices. Sociocultural theory using Vygotsky's (1978) lens on mediation of human behavior through tools, symbols, and artifacts can provide insights and understanding of ICT integration in teaching and learning.

In sociocultural theory framework, the teacher is the mediator of the available tools, guiding students to become active and engaged with the tools in the social environment during the learning process (Subramaniam, 2007). Technology in and of itself does not lead to improved communication or knowledge creation, but human behavior and creative uses of the technology may lead to innovative ways of using technology (Somekh, 2007). Therefore, there is a need for deeper understanding of teacher characteristics (e.g., education levels, self-efficacy), school contexts, and professional development related to ICT use in order to understand teachers' ICT use.

Moreover, sociocultural theory can provide a framework for analysis of ICT use among student groups in the school setting, beyond the school walls, and it can also examine how teachers' ICT use impacts students' learning. The development of coherent systems takes multiple stakeholders, iterations, time, and a conducive school climate focused on continuous improvement and understanding of tacit knowledge present in these environments (Fullan, 2015; Somekh, 2007). In the classroom, teachers' ICT use may differ depending on pedagogical approaches (student centered vs. teacher centered) or on the classroom composition of students contributing to differential learning experiences with ICT. Understanding these nuances in the classroom can assist educators, policy developers, and school administrators in enacting measures that encourage appropriate pedagogies, increase quality instruction with ICT, and inform the development of professional development activities that promote student-centered and equity-focused pedagogy.

Technology Pedagogical and Content Knowledge Framework (TPACK)

The sociocultural theoretical framework is evident in understanding the technology, pedagogy, content, and knowledge (TPACK) framework. Koehler and Mishra (2009) build on Schulman’s (1986) Pedagogical Content Knowledge framework by adding the technological knowledge necessary for ICT integration. Often, teachers are expected to demonstrate the different knowledge capacities when integrating ICT. However, since teachers exist in a larger system, Voogt (2013) posits that the TPACK framework needs to exist in a wider context beyond an individual teacher. Lastly, as countries around the world embrace ICT, it is likely that tensions will arise between global standards for ICT use and local perspectives on the role of ICT in teaching and learning. It is imperative then for countries to embed ICT and global policies (e.g., 21st century skills) with awareness of local contexts to avoid blind acceptance of foreign policies that may not meet the needs of local contexts, may overburden the existing systems, and may cause deleterious effects in teaching and learning outcomes (Sewlyn, 2012).

Niess (2005) worked with preservice mathematics and science teachers enrolled in a class for integrating technology. The study identified themes that can accompany TPACK mathematics instruction. These themes highlighted the importance of teachers understanding the purpose of incorporating technology in teaching mathematics and of teachers demonstrating students’ knowledge development with technology, mathematics curricula, and instructional practices. To elaborate, when teachers understand the purpose of incorporating technology, they can engage students in making connections about the science present in the technology, which can lead to deeper learning and meaning-making. Technology-based instruction has potential to shift teacher-centered practices to become more student-centered. Niess highlights this shift in the study as the preservice teachers focus more on their students learning process instead of their teaching practice (Niess, 2005). Content-specific curricula is important when using technology as this content knowledge guides ICT use. Overall, this preservice study showed the different ways that the TPACK domain plays out in a classroom. In a recent study, Durak (2021) found that teachers' technology integration self-efficacy and attitudes towards technology were significant predictors of teachers' TPACK levels, highlighting the role of teachers' beliefs and attitudes towards technology in the development of the different knowledge domains.

Using data from the 2013 TALIS mathematics questionnaire, this present study investigates how teachers used ICT in mathematics instruction and what the factors were that contributed to their ICT use.

Research Questions

1. What is the relationship between professional qualifications (e.g., technology training, years of teaching experience) and teachers' ICT use in mathematics instruction?
2. Which school contexts predict ICT use?

Methodology

Data Source and Sample

To answer the two research questions, I used data from the TALIS 2013 dataset. TALIS 2013 is one of the largest international surveys with a focus on the learning and teaching environment. The survey drew school and teacher level data from 33 countries (twenty-four OECD countries and nine partner countries). The data were collected from 10,000 schools and more than 170,000 teachers. The international sampling plan was a stratified two-stage probability sampling design. Teachers were randomly selected from randomly selected schools. TALIS was conducted to collect data that would provide directions in policy development on teacher feedback, professional development, and school contexts (OECD, 2013). The analytic sample in this study includes mathematics teachers of 15-year-old students from the sampled PISA schools (OECD, 2013). The analytic sample consists of 6,570 teachers from eight countries: Australia, Finland, Latvia, Mexico, Portugal, Romania, Singapore, and Spain. The teachers from these sampled countries participated in the 2012 PISA and completed the additional mathematics questionnaire.

Table 1 shows some similarities and differences between the countries in the analytic sample. Table 1 shows that 75% of the countries in the analytic sample are high-income countries similar to the U.S (World Bank, 2016). Most of the countries are OECD member countries and all the countries participated in the 2012 PISA mathematics assessment (OECD, 2012). The TALIS-PISA link provided information on teaching practices at the classroom level. It is important to note that the TALIS (2014) technical report states that the TALIS results will not be used to interpret the students' scores on the PISA, but the results should instead be used to understand teachers'/principals' responses about the learning and teaching environment (OECD, 2013). As an example, for this analysis the focus is on teachers' ICT use in their mathematics instruction and student characteristics at the classroom level that contribute to ICT use, but the analysis does not extend the findings to students' mathematics performance. However, the findings from this analysis can inform current practices about ICT use in mathematics instruction in contexts such as the United States.

Table 1

Similarities and Differences of the Countries

Countries	OECD Member Countries	OECD Partner Countries	PISA 2012 (math)	Upper Middle-Income	High-Income	European	Non-European
Australia	x		x		x		x
Finland	x		x		x	x	
Latvia		x	x		x	x	
Mexico	x		x	x			x
Portugal	x		x		x	x	
Romania		x	x	x		x	
Singapore		x	x		x		x
Spain	x		x		x	x	

Note: Sources. OECD (2012); World Bank (2016); OECD = organization for economic cooperation and development; PISA = programme for international student achievement.

Measures

Outcomes

For both Research Question 1 and 2, I examine how teachers used ICT in mathematics instruction. The teachers were asked how they used ICT in mathematics instruction for each task: drill and practice, topic-specific activities, spreadsheets/data analysis, assessment, and internet resources. The original response scale was a four-point scale: (1) Never or almost never, (2) Occasionally, (3) Frequently, or (4) Always or almost always. I recoded the variable to a two-point scale: (0) Never or almost never/occasionally, (1) Frequently/always or almost always, because preliminary analysis of the distribution showed the data were skewed with teachers using ICT infrequently.

Teacher-Level Predictors

For Research Question 1, I examined the relationship between professional qualifications (e.g., technology training, years of teaching experience) and teachers' ICT use in mathematics instruction. I examined a range of teacher professional qualifications that may be associated with teachers' ICT use. All scales selected for this study were previously validated and demonstrate strong reliability and validity. The items in each scale are available in the TALIS technical report (OECD, 2014). The International Standard Classification of Education (ISCED) is a framework for grouping academic levels in four categories that provide internationally comparable levels of education (UNESCO Institute of Statistics, 2017). The four levels are a) primary education b) lower secondary education, c) upper secondary education, and d) post-secondary level. Teacher qualifications included measures for technology training, education level (Level 5A or higher on the ISCED), whether the teacher attended a teacher education program, and teaching experience in years. I also examine teacher cooperation related to teacher relationships with colleagues. The teacher cooperation variable consists of eight items related to the exchange of teaching ideas and professional collaboration.

School-Level Predictors

For Research Question 2, I examined whether school contexts are associated with how teachers use ICT in mathematics instruction. For school leadership, I used the distributed leadership scale that measured participation in decision-making and whether teachers experienced a collaborative culture of mutual support. Lastly, I included a variable that asked teachers whether they received administrators' support.

Analysis

I addressed the research questions using descriptive statistics and linear regression models using STATA version 14.0. I incorporated survey weights to ensure the population estimates are effectively adjusted. For Research Question 1, to examine the relationship between teachers' instructional approaches, beliefs, and ICT use in mathematics instruction, I fitted the following regression model:

$$logit(p_{ij}) = \beta_{0j} + \gamma X_{ij}$$

I fitted separate models for each outcome variable (i.e., each ICT task). In this model, p_{ij} is the probability of mathematics teachers' ICT use in instruction for teacher *i* in school *j*; X_{ij} represents a vector of teachers' professional qualifications with γ as a vector of the associated coefficients. For Research Question 2, to examine the relationship between school contexts and ICT use in mathematics instruction, I fitted the following regression model:

$$logit(p_{ij}) = \beta_{0j} + \omega C_{ij}$$

I fitted separate models for each outcome variable (i.e., each ICT task). In this model, p_{ij} is the probability of mathematics teachers' ICT use in instruction for teacher *i* in school *j*; C_{ij} represents a vector of school context variables with ω as a vector of the associated coefficients.

Results

Descriptive Characteristics of Mathematics Teachers

Table 2 shows a descriptive summary of the mathematics teachers in the analytic sample. Spain had the largest representation of teachers, who made up 21% of the sample, while Mexico and Romania both had a close representation of teachers, at 8% each. It is also evident from Table 2 that the teachers were mainly from European countries and more than 50% of the teachers had at least 17 years of teaching experience. Table 3 displays a descriptive summary (i.e., means and standard deviations) of the variables used in the analyses. UNESCO developed the International Standard Classification of Education (ISCED) as a framework for grouping academic levels in four categories. The four levels are a) primary education, b) lower secondary education, c) upper secondary education, and d) post-secondary level.

Table 2

Sample Demographics: Descriptive Statistics

Variable	N	%
Countries		
Australia	859	13.1
Finland	1027	15.6
Latvia	334	5.1
Mexico	511	7.8
Portugal	683	10.4
Singapore	1176	17.9
Spain	1428	21.7
Romania	522	8.4
Teaching Experience		
0 – 17	3654	57.6
18 – 35	2423	38.0
36 – 50+	272	4.0

Table 3

Means and Standard Deviations of Mathematics Teachers

Variable	*M*	*SE*
Professional Qualifications		
Teaching Experience	16.56	0.39
Formal Education (ISCED 5A/6)	0.96	0.01
Teacher Training	0.68	0.02
Training in Technology During In-service	0.75	0.02
School Environment		
Collaborative Culture	0.70	0.02
Administrators' Support	0.77	0.02
Teacher Cooperation	10.08	0.09
Participation in Decision Making	0.63	0.02
Teachers' ICT Use		
Drill and Practice Software	1.73	0.03
Topic-Specific Software	1.85	0.03
Spreadsheets/Data Analysis	1.66	0.03
Assessing Student Learning	1.63	0.03
Internet Resources	2.38	0.04

Note. ICT = information communication technology; ISCED = international standard classification of education.

Collaborative culture, administrators' support, and teacher participation in decision-making were all on a 0 to 1 scale. More mathematics teachers acknowledged receiving administrators' support than participating in decision-making. According to the TALIS technical report, the teacher cooperation measured the frequency of teachers exchanging materials with colleagues, observing peers' classes, and giving feedback.

A score above 10 shows consistent repetition of activities included in the teacher cooperation scale. Table 3 shows that teachers in the sample participated in activities that promoted teacher cooperation. Finally, the teachers' ICT use variable was on a scale of 1–4 and measured the frequency of teachers' ICT use in instruction during the school year. Table 3 shows that teachers mostly incorporated internet resources (rather than ICT) for drill and practice, topic-specific activities, spreadsheets/data analysis, or for assessment purposes.

Research Question One: Teachers' Professional Qualifications and ICT Use

Scholars have attributed ICT use to teachers' professional qualifications (e.g., education levels, teacher training). To examine the teachers' professional qualifications that predicted ICT use, I fitted a separate model for each ICT task and conducted logistic regression analyses. An odds ratio of one represents the probability of teachers' ICT use compared to the reference category for each predictor. For instance, the reference category for teacher training includes teachers who did not receive teacher training. Table 4 shows the teachers' professional qualifications as predictors and the odds ratios of ICT use across all five ICT tasks. Education level was a significant predictor for ICT in drill and practice, spreadsheets/data analysis activities, and assessment. Mathematics teachers with ISCED education levels 5A and 6 had statistically significant higher odds of using ICT in these activities compared to mathematics teachers with ISCED education levels of 5b or lower ($p < 0.05$). In summary, education levels were associated with mathematics teachers' use of ICT for drill and practice, spreadsheets/data analysis, and assessment in instruction.

Table 4

Logistic Regression Results in Odds Ratios for Model Including Teachers' Professional Qualifications Predictors of ICT Use

	Drill and practice activities	Topic specific activities	Spreadsheets/ Data analysis activities	Assessment activities	Internet Resources
Constant	0.121**	0.398	0.169**	0.189**	0.624
Education (5A or 6)	2.685*	0.446	4.413**	3.292*	1.234
Teacher training	1.127	1.887	0.239***	0.554	1.002
Teaching exp. **(ref = less than 5 years)**					
5-10 years	1.209	1.021	0.825	0.622	0.534*
More than 10 years	0.739	0.938	1.045	0.613	0.656*
Technology training	0.713	0.645	1.252	0.968	1.117
N	4934	4936	4923	4930	4941

Note. All models controlled for country effects. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Research Question Two: School Contexts and Teachers' ICT Use

I conducted logistic regression analyses to examine school context predictors (i.e., teacher cooperation, participation in decision-making, collaborative culture, administrative support) on teachers' ICT use. The results in odds ratios are shown in Table 5**.** Teacher cooperation was associated with ICT use in mathematics instruction in three out of the five ICT tasks (p < 0.05). In contrast, teachers' participation in school decision-making, the presence of a collaborative culture, and teachers' receipt of administrative support were not associated with teachers' ICT use as shown in Table 5 (p > 0.05).

Table 5

Logistic Regression Results in Odds Ratios for Model Including School Context Predictors of ICT Use

	Drill and practice activities	Topic specific activities	Spreadsheets/data analysis activities	Assessment activities	Internet Resources
Constant	0.032^{***}	0.142^{**}	0.056^{**}	0.026^{***}	0.137^{*}
Teacher Cooperation	1.222^{*}	1.130	1.093	1.205^{*}	1.189^{**}
Decision Making	1.377	1.292	1.982	1.493	1.397
Collaborative Culture	0.808	1.018	0.890	0.576	1.082
Administrative Support	0.934	0.358^{**}	0.883	1.517	0.427^{**}
N	5052	5053	5043	5051	5061

Note. All models controlled for country effects. $^{*}\ p < 0.05$, $^{**}\ p < 0.01$, $^{***}\ p < 0.001$.

Discussion

This study provides an international analysis on how teachers used ICT in mathematics instruction across eight countries (i.e., Australia, Finland, Latvia, Mexico, Portugal, Romania, Singapore, and Spain) to develop a richer understanding about ICT use that may inform policy development and professional development programs in similar contexts. Understanding the ways that teachers use ICT in instruction and contributing factors can provide insights into policy development. Scholars in the field have identified and documented factors that predict teachers' ICT use. These include teacher professional development, social and organizational culture, teacher beliefs, and school leadership (Ertmer & Ottenbreit-Leftwich, 2010; Frank et al., 2011;

Fullan, 2015; Hughes, 2005). Additionally, elements such as compatibility with current instructional practices and beliefs, level of complexity with adopting innovative practices (e.g., ICT, blended learning), affordances from the innovation, and the role of time in implementing the innovation are all factors that impact the uptake of innovations (Rogers, 1995). Classrooms and schools are social environments that may contribute to student and teacher learning. Furthermore, the sociocultural theory argues that learning is culturally mediated and involves beliefs, practices, and knowledge of multiple stakeholders in a social environment.

Research Question One: Teachers' Professional Qualifications and ICT Use

The one professional qualification that predicted ICT use was teachers' education level. High education levels (i.e., 5A or 6) was associated with teachers' ICT use except for topic-specific activities and use of internet resources. One plausible reason that may have contributed to the impact of teachers' education levels on their ICT use is exposure to technology during their education experience. Additionally, teachers with higher education levels may have incorporated ICT in instruction as a result of the relative advantages offered through ICT (Rogers, 1995). These advantages include providing students with opportunities to practice earlier learned mathematics concepts using a medium other than paper and pencil, organizing statistical information using spreadsheets, and visually conducting data analysis. However, mathematics teachers with lower education levels had higher odds of incorporating topic-specific software in instruction. A connection between education levels and teachers' ICT use for topic-specific activities would seem to be directly related; that is, higher education levels would increase the teachers' odds of using ICT for topic-specific activities; this was not the case in the current study. This could be because teachers with education levels of 5A and below may have acquired information about incorporating ICT in these activities from different sources or through personal exploration and learning.

It was unsurprising that teacher training was not associated with teachers' ICT use. This finding is plausible especially if the training is not focused on teachers integrating ICT in mathematics instruction. Scholars (e.g., Ertmer & Ottenbreit-Leftwich, 2010; Hughes, 2005) have argued that teaching may require awareness of one's beliefs about teaching and learning before any change can occur. In addition, teachers may need specific knowledge to successfully incorporate ICT in teaching. In the TPACK framework, Koehler and Mishra (2009) provide the various kinds of teacher knowledge required for effective ICT integration. These include content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technology knowledge (TK), technology pedagogical knowledge (TPK), and technology content knowledge (TCK). Koehler and Mishra (2009) further argue that teachers often conceptualize TK separate from CK and PK, and this subsequently contributes to fragmented understanding and practice of TK, instead of teachers' understanding of the relationships and overlaps with TK, CK, and PK. For effective and strategic integration of ICT in teaching and learning, teachers can benefit from professional development that meshes content and pedagogy, ensuring that pedagogy is the main driver of ICT use.

Relatedly, the findings show that technology training predicted higher odds of mathematics teachers' ICT use for spreadsheets/data analysis and internet resources. This finding is similar to that of Willis et al. (2018), who reported a positive association between teachers' higher levels of computer skills and purposeful use of ICT in mathematics instruction. A plausible reason for the higher likelihood of teachers' use of ICT for spreadsheets/data analysis is the specialized nature of this ICT task, which requires a certain level of technology training. On the other hand, the versatility provided through internet resources may have contributed to the increased likelihood of teachers' using these internet resources in instruction. However, the findings showed that these odds were not different from teachers without technology training.

Teachers with teaching experience and a strong grasp of content pedagogy are more likely to use ICT in ways that provide students with opportunities to participate in high-level tasks (Hughes, 2005). However, the findings in this study show that years of teaching experience was not associated with teachers' use of ICT in instruction. This finding could be attributed to prior teachers' experiences when incorporating ICT. Comparatively, teachers with fewer than five years of teaching experience had higher odds of incorporating ICT in instruction for spreadsheets/data-analysis, assessment, and internet resources. The novelty of ICT use may incentivize these teachers to incorporate ICT more, compared with teachers with more years of teaching experience.

Examining teachers' ICT use across the various tasks using the TPACK framework can provide further insights on knowledge skills that teachers are likely to demonstrate in mathematics instruction. According to Koehler and Mishra (2009), TK refers to knowledge about the technology and its affordances; CK refers to knowledge about the subject matter; PK refers to a teacher's understanding of students' thinking and learning; PCK refers to a teachers' understanding of the interaction between the content and the methods of teaching the content; TPK refers to a teacher's understanding of ways of using the technology with specific content while integrating appropriate methods to promote learning; and TPACK refers to a deeper understanding of the interactions and constraints among the three domains of knowledge in order to effectively integrate and harness ICT in instruction. The TPACK framework can provide a lens to examine ways in which the different constructs interact in instructional practices (Agyei

& Voogt, 2012; Graham et al., 2012). Bos (2011) argued that when integrating ICT in mathematics instruction, teachers require cognitive awareness of the various content, pedagogical, and technological knowledge required: for instance, in teaching abstract mathematical concepts with ICT.

In this study, out of the five ICT tasks, certain tasks could be considered more content-specific than others, requiring specific teacher knowledge for effective integration in instruction. For instance, teachers who incorporated ICT for topic-specific activities and spreadsheets/data-analysis, which relate directly to the mathematics content area and involve making abstract mathematical concepts concrete, required TPACK. On the other hand, TK is required when teachers incorporated ICT for drill and practice or assessment activities because the primary focus was on students practicing or demonstrating learned skills (Graham et al., 2012; Kaput et al., 2007). When incorporating ICT for assessment purposes, teachers may have required PK as they used the assessment data to evaluate student progress. Lastly, in this study, teachers used internet resources most frequently mainly due to the breadth of affordances (e.g., drill and practice, assessment, interactive activities) available through the internet. It is likely that teachers demonstrated TPK when using internet resources as this construct captures a wide range of knowledge skills and general teaching strategies (Graham et al., 2012; Hughes, 2013).

Research Question Two: School Contexts and ICT Use

The school context included teacher cooperation, participation in decision-making, presence of a collaborative culture, and administrative support. Teacher cooperation predicted higher odds of teachers' ICT use in mathematics instruction in drill and practice, assessment, and internet resources. This finding can be extrapolated to show that when teachers work together, they are likely to learn, share ideas on ways to integrate, and use ICT in mathematics instruction, all leading to increased frequency of ICT use. Further, teacher cooperation can provide teachers with support as they become more willing to take risks in using ICT (Overbay et al., 2010). Engaging in innovative teaching practices such as integrating ICT can involve an element of risk-taking. Literature documents the role of peer-to-peer support as a vehicle that facilitates the diffusion of innovations. Therefore, although teacher cooperation was associated with ICT use for three out five tasks, this shows potential in its role on influencing greater ICT use in instruction. Peer-to-peer support can also provide teachers with opportunities to develop TPACK as they develop confidence and interact with different ICT in instruction (Galanouli et al., 2004).

Overbay et al. (2010) reported that administrator support was not a significant predictor of teachers' ICT use. This current study showed administrator support reduced the likelihood of teachers' ICT use except for assessment purposes. This finding can be explained by existing school policies on ICT use or an administrators' leadership styles. For instance, if a school administrator offers support but has a leadership style incompatible with envisioning ICT as effective for teaching mathematics, the support may not be geared towards ICT use in instruction and may not promote teachers' ICT use. Administrators play a critical role in determining school culture, including a culture of innovation such as using ICT for instruction (Fullan, 2015). In thinking about sociocultural theory, school culture can result from teachers' active participation in decision-making or collaboration among stakeholders (Overbay et al., 2010; Somekh, 2007; Whipp et al., 2005). However, participation in decision-making and the presence of a collaborative culture was not associated with teachers' ICT use in mathematics instruction. This finding highlights the possibility that teachers and stakeholders at a school may participate in decision-making and collaborate in tasks unrelated to ICT use, translating to limited effects on ICT use (Ertmer et al., 2012).

A shared vision of the role of ICT in mathematics instruction can focus teacher collaboration and participation in decision-making towards effective use of ICT and may contribute to increased use of ICT in the future. More importantly, beyond ICT, a shared vision may provide stakeholders with opportunities to identify critical drivers of change, such as curricular and pedagogical changes (Fullan, 2015; Warschauer et al., 2014). The TPACK framework shows that the various knowledge domains work in tandem and not individually for a single teacher. Therefore, when understanding teachers' ICT use, it is imperative for stakeholders to consider a holistic approach. In addition, a teacher exists in a social system consisting of different factors that contribute to a teacher's activity. For a deeper understanding of teachers' ICT use, these factors need to be understood to further understand the context of ICT use.

Similar to the U.S., countries in this analytic sample showed limited overall ICT use in mathematics instruction. This may imply that the challenges between countries facing ICT integration are similar, and countries may benefit from learning from each other about successes and challenges, with the hope of effective utilization of scarce resources and transformed student learning experiences. In the next section, I discuss limitations and implications for practice.

Limitations

There are a number of limitations in this study. First, although the study includes a large number of participants, it was done with a specific population of teachers from OECD member and partner countries. Although the analytic sample included some participants from low-income countries participating in the PISA, teachers were mainly from high-income countries. This scope limits the generalizability of the findings to wider populations of teachers in different countries. Second, although TALIS (2013) provides rich information about teachers' learning and working conditions, the questions in the survey may not be neutral. This means that, among the participating teachers, the questions may have different interpretations, and there may be differences in the definition of words, concepts, and starting points when assessing oneself or assessing school contexts, which may cause subjectivity in the information gathered. Additionally, the countries in the sample may have varied policies on ICT or ICT resources that may affect teachers' use of ICT that is not captured in the data. Third, the level of integration of ICT in a school or country may be different among these countries and this may influence teachers' ICT use. Finally, the analyzed data in this study is over five years old and classrooms have a variety of ICT; however, teachers' ICT use is still gradually changing and therefore the information in this manuscript remain relevant. Additionally, some of the ICT introduced in mathematics classroom closely mirror the types highlighted in this study.

Conclusion

To summarize, this study sought to examine teachers' use ICT in mathematics instruction and the associated factors that predict teachers' ICT use. This information can allow stakeholders (e.g., policy makers, curriculum developers, teachers, researchers) to understand whether teachers actually incorporate ICT into mathematics instruction. Additionally, the study investigated potential factors associated with ICT use in mathematics instruction. For instance, teacher education levels and teacher cooperation were associated with teachers' ICT use. If stakeholders care about the return on investment from ICT in schools, and largely how ICT affect students' learning, understanding how teachers use ICT and contributing factors that influence teachers' ICT use can allow administrators, professional developers, and other stakeholders to target policies that promote effective ICT use.

Results from this analysis can inform professional development topics and activities on instructional practices that align with ICT and promote effective ICT use in teaching. These efforts can inform decisions on ICT use that enhance instead of hinder student learning, especially in mathematics, while ensuring efficient utilization of scarce resources. As technology costs decrease and schools become more internet connected and networked, challenges related to access are quickly becoming less pronounced. However, further challenges exist when it comes to ICT integration that transcends barriers related to access that promote high-level thinking, creativity, and student-centered learning.

Future Research and Implications for Practice

There is a need for continued qualitative and quantitative research on the ecological perspectives of ICT in instruction to uncover, unlock, and maximize the potential of ICT use in instruction. Despite investments in technology, ICT remains on the periphery especially in mathematics instruction. Researchers and practitioners may find it beneficial to collaborate in action research in an attempt to understand potential barriers not captured through questionnaires. Including students in these discussions can provide a student perspective and reveal critical aspects of ICT use often overlooked. Action research can be incorporated as a paradigm for change as stakeholders (e.g., teachers, researchers) work together to uncover assumptions about ICT in teaching and learning and most importantly, bring teacher voices and knowledge into the development of policies around innovations such as ICT.

Teacher education programs can require a strategic and intentional focus on adequately preparing teachers on effective ways of integrating ICT in instruction. This would ensure that new teachers are equipped with relevant skills beyond the compartmentalized knowledge of content, technology, and pedagogy. Teacher education programs can incorporate courses on design thinking that actively involve preservice teachers in the development of context-specific activities that can boost their development of TPACK and exposure to a range of ICT affordances and constraints. Teachers can also benefit from developing skills for designing learning environments that incorporate pedagogy-based ICT activities in mathematics instruction, activities that promote student engagement, interest, authentic learning, and growth (Fullan & Hargreaves, 2016).

Overall, this analysis provides evidence of the need for context-specific ICT training for teachers. Both micro and macro factors may hinder teachers from integrating ICT in instruction. In addition, school leaders may benefit from developing a shared vision for ICT in instruction, building capacities, collaborative cultures, and communities of practice to promote teacher cooperation and collaboration**.** Policy makers and curriculum developers can consider aligning mathematics curriculum with ICT goals to provide a clearer path for teachers on the role of ICT in teaching and learning. This alignment of the curriculum, goals, and the role of ICT in teaching and learning, together with the development of a shared vision, can facilitate coherence within complex educational systems (Fullan et al., 2015). Continued research is required to understand the nuances among the different ICTs introduced in mathematics and in STEM classes more broadly. This includes gaming technologies, artificial intelligence, and assistive technologies.

References

Agyei, D., & Voogt, J. (2012). Developing technological pedagogical content knowledge in pre-service mathematics teachers through collaborative design. *Australasian Journal of Educational Technology, 28*(4), 547–564. https://doi.org/10.14742/ajet.827

Akiba, M. (2017). Editor's introduction: Understanding cross-national differences in globalized teacher reforms. *Educational Researcher*, *46*(4), 153–168. https://doi.org/10.3102/0013189X17711908

Altrichter, H., & Posch, P. (2009). Action research, professional development and systemic reform. In S. E. Noffke & B. Somekh (Eds.), *The SAGE handbook of educational action research* (pp. 213–225). Sage Publications Ltd.

Bain, A., & Weston, M. A. (2012). *The learning edge: What technology can do to educate all children*. Teachers College Press.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, *33*(8), 3–15. https://doi.org/10.3102/0013189X033008003

Bos, B. (2011). Professional development for elementary teachers using TPACK. *Contemporary Issues in Technology and Teacher Education*, *11*(2), 167–183. https://citejournal.org/volume-11/issue-2-11/mathematics/professional-development-for-elementary-teachers-using-tpack

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research–A systematic review of recent trends. *Computers & Education*, 114, 255–273. https://doi.org/10.1016/j.compedu.2017.07.004

Chen, B. (2015). Exploring the digital divide: The use of digital technologies in Ontario public schools. *Canadian Journal of Learning and Technology*, *41*(3). https://doi.org/10.21432/T2KP6F

Clarke, B., Doabler, C., & Nelson, N. (2014). Best practices in mathematics assessment and interventions with elementary students. In P. Harrison & A. Thomas (Eds.), *Best practices in school psychology: Data-based and collaborative decision making* (6th ed., pp. 219–232). National Association of School Psychologists.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Harvard University Press.

Cuban, L. (2013). *Inside the black box of classroom practice: Change without reform in American education*. Harvard Education Press.

Darling-Hammond, L. (2010). Teacher education and the American future. *Journal of Teacher Education*, *61*(1-2), 35–47. https://doi.org/10.1177/00224871093480

De Witte, K., & Rogge, N. (2014). Does ICT matter for effectiveness and efficiency in mathematics education? *Computers & Education*, *75*, 173–184. https://doi.org/10.1016/j.compedu.2014.02.012

Ditzler, C., Hong, E., & Strudler, N. (2016). How tablets are utilized in the classroom. *Journal of Research on Technology in Education*, *48(3)*, 181–193. https://doi.org/10.1080/15391523.2016.1172444

Durak, H. Y. (2021). Modeling of relations between K-12 teachers' TPACK levels and their technology integration self-efficacy, technology literacy levels, attitudes toward technology and usage objectives of social networks. *Interactive Learning Environments*, *29*(7), 1136–1162. https://doi.org/10.1080/10494820.2019.1619591

El Yacoubi, N. (2013). Impediment and challenges of innovations in mathematics education in Africa. *Africa Education Review*, *10*(1), S75–S88. https://doi.org/10.1080/18146627.2013.855433

Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research and Development*, *53*, 25–39. https://doi.org/10.1007/BF02504683

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, *42*(3), 255–284. https://doi.org/10.1080/15391523.2010.10782551

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education*, *59*(2), 423–435. https://doi.org/10.1016/j.compedu.2012.02.001

Evans, M. A., Nino, M., Deater-Deckard, K., & Chang, M. (2015). School-wide adoption of a mathematics learning game in a middle school setting: Using the TPACK framework to analyze effects on practice. *The Asia-Pacific Education Researcher*, *24*, 495–504. https://doi.org/10.1007/s40299-014-0225-y

Frank, K. A., Zhao, Y., Penuel, W. R., Ellefson, N., & Porter, S. (2011). Focus, fiddle, and friends: Experiences that transform knowledge for the implementation of innovations. *Sociology of Education*, *84*(2), 137–156. https://doi.org/10.1177/0038040711401

Friedman, T. L. (2005). *The world is flat: A brief history of the twenty-first century*. Farrar, Straus and Giroux.

Fullan, M. (2015). *The new meaning of educational change* (5th ed.). Teacher College Press.

Fullan, M., & Hargreaves, A. (2016). *Bringing the profession back in: Call to action*. Learning Forward. https://michaelfullan.ca/wp-content/uploads/2017/11/16_BringingProfessionFullanHargreaves2016.pdf

Fullan, M., Rincon-Gallardo, S., & Hargreaves, A. (2015). Professional capital as accountability. *Education Policy Analysis Archives, 23*(15). https://doi.org/10.14507/epaa.v23.1998

Galanouli, D., Murphy, C., & Gardner, J. (2004). Teachers' perceptions of the effectiveness of ICT-competence training. *Computers & Education*, *43*(1-2), 63–79. https://doi.org/10.1016/j.compedu.2003.12.005

Glassett, K., & Schrum, L. (2009). Teacher beliefs and student achievement in technology-rich classroom environments. *International Journal of Technology in Teaching and Learning*, *5*(2), 138–153. https://nsuworks.nova.edu/fse_facarticles/189

Graham, C., Borup, J., & Smith, N. B. (2012). Using TPACK as a framework to understand teacher candidates' technology integration decisions. *Journal of Computer Assisted Learning, 28*(6), 530–546. https://doi.org/10.1111/j.1365-2729.2011.00472.x

Guglielmi, R. S., & Brekke, N. (2017). A framework for understanding cross-national and cross-ethnic gaps in math and science achievement: The case of the United States. *Comparative Education Review, 61*(1), 176–213. https://doi.org/10.1086/689656

Hardman, J. (2019). Towards a pedagogical model of teaching with ICTs for mathematics attainment in primary school: A review of studies 2008–2018. *Heliyon*, *5*(5). https://doi.org/10.1016/j.heliyon.2019.e01726.

Hennessy, S., Ruthven, K., & Brindley, S. (2005). Teacher perspectives on integrating ICT into subject teaching: Commitment, constraints, caution, and change. *Journal of Curriculum Studies, 37*(2), 155–192. https://doi.org/10.1080/0022027032000276961

Hilton, A. (2018). Engaging primary school students in mathematics: Can iPads make a difference? *International Journal of Science and Mathematics Education, 16*(1), 145–165. https://doi.org/10.1007/s10763-016-9771-5

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020). The difference between emergency remote teaching and online learning. EDUCAUSE Review, 3. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remoteteaching-and-online-learning

Howard, S. K., Chan, A., & Caputi, P. (2015). More than beliefs: Subject areas and teachers' integration of laptops in secondary teaching. *British Journal of Educational Technology, 46*(2), 360–369. https://doi.org/10.1111/bjet.12139

Hughes, J. (2005). The role of teacher knowledge and learning experiences in forming technology-integrated pedagogy. *Journal of Technology and Teacher Education, 13*(2), 277–302. https://www.learntechlib.org/primary/p/26105/.

Hughes, J. E. (2013). Descriptive indicators of future teachers' technology integration in the PK-12 classroom: Trends from a laptop-infused teacher education program. *Journal of Educational Computing Research, 48*(4), 491–516. https://doi.org/10.2190/EC.48.4.e

Hughes, J. E., & Read, M. F. (2018). Student experiences of technology integration in school subjects: A comparison across four middle schools. *Middle Grades Review, 4*(1). https://scholarworks.uvm.edu/mgreview/vol4/iss1/6

Kaput, J. J., Lesh, R. A., & Hegedus, S. (2007). Technology becoming infrastructural in mathematics education. In R. A. Lesh, E. Hamilton, & J. J. Kaput (Eds.), *Foundations for the future of mathematics education* (pp. 172–192). Routledge.

Ke, F. (2008). A case study of computer gaming for math: Engaged learning from gameplay? *Computers and Education, 51*(4), 1609–1620. https://doi.org/10.1016/j.compedu.2008.03.003

Koehler, M. J. & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1). https://citejournal.org/volume-9/issue-1-09/general/what-is-technological-pedagogicalcontent-knowledge

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Li, S. C., & Pow, J. W. (2011). Affordance of deep infusion of one-to-one Tablet-PCs into and beyond the classroom. *International Journal of Instructional Media, 38*, 319–326. https://go.gale.com/ps/i.do?p=AONE&u=googlescholar&id=GALE|A268478396&v=2.1&it=r&sid=AONE&asid=2d9ea136

Lingard, B., Martino, W., & Rezai-Rashti, G. (2013). Testing regimes, accountabilities and education policy: Commensurate global and national developments. *Journal of Education Policy*, *28*(5), 539–556. https://doi.org/10.1080/02680939.2013.820042

McClanahan, B., Williams, K., Kennedy, E., & Tate, S. (2012). A breakthrough for Josh: How use of an iPad facilitated reading improvement. *TechTrends*, *56*, 20–28. https://doi.org/10.1007/s11528-012-0572-6

McFarland, J., Hussar, B., de Brey, C., Snyder, T., Wang, X., Wilkinson-Flicker, S., Gebrekristos, S., Zhang, J., Rathbun, A., Barmer, A., Bullock Mann, F., & Hinz, S. (2017). The Condition of Education 2017 (NCES 2017-144). U.S. Department of

Education. Washington, DC: National Center for Education Statistics. Retrieved [22nd March 2023]. https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2017144

McKenna, C. (2012). There's an app for that: How two elementary classrooms used iPads to enhance student learning. *Education, 2*(5), 136–142. https://doi.org/10.5923/j.edu.20120205.05

McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., & Bassett, K. (2016). Teaching in a digital age: How educators use technology to improve student learning. *Journal of Research on Technology in Education*, *48*(3), 194–211. https://doi.org/10.1080/15391523.2016.1175856

Moll, L. C. (Ed.). (1990). *Vygotsky and education: Instructional implications and applications of sociohistorical psychology.* Cambridge University Press.

Mouza, C. (2008). Learning with laptops: Implementation and outcomes in an urban, under-privileged school. *Journal of Research on Technology in Education*, *40*(4), 447–472. https://doi.org/10.1080/15391523.2008.10782516

Musti-Rao, S., & Plati, E. (2015). Comparing two classwide interventions: Implications of using technology for increasing multiplication fact fluency. *Journal of Behavioral Education*, *24*, 418–437. https://doi.org/10.1007/s10864-015-9228-x

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. https://doi.org/10.1016/j.tate.2005.03.006

Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper, S. R., Johnston, C., Browning, C., Özgün-Koca, S. A., & Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 4–24. https://www.learntechlib.org/primary/p/29448/

OECD. (2014). *TALIS 2013 technical report.* https://www.oecd.org/education/school/TALIS-technical-report-2013.pdf

Ok, M. W., & Bryant, D. P. (2016). Effects of a strategic intervention with iPad practice on the multiplication fact performance of fifth-grade students with learning disabilities. *Learning Disability Quarterly*, *39*(3), 146–158. https://doi.org/10.1177/0731948715598285

OECD. (2019). Country note. Programme for international student assessment (PISA) results from PISA 2018. https://www.oecd.org/pisa/publications/PISA2018_CN_USA.pdf

OECD. (2013). *TALIS – The OECD Teaching and Learning International Survey* [Data set]. https://www.oecd.org/edu/school/talis.htm

Overbay, A., Patterson, A. S., Vasu, E. S., & Grable, L. L. (2010). Constructivism and technology use: Findings from the IMPACTing Leadership project. *Educational Media International*, *47*(2), 103–120. https://doi.org/10.1080/09523987.2010.492675

Peck, C., Hewitt, K. K., Mullen, C. A., Lashley, C., Eldridge, J., & Douglas, T. M. O. (2015). Digital youth in brick and mortar schools: Examining the complex interplay of students, technology, education, and change. *Teachers College Record*, *117*(5), 1–40. https://doi.org/10.1177/016146811511700505

Pont, B. (2018). A comparative view of education system reform: Policy, politics, and people. In Malone, H. J., Rincon-Gallardo, S., & Kew, K. (Eds.), *Future directions of educational change: Social justice, professional capital, and systems change* (pp. 171–187). Routledge.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). Free Press.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context.* Oxford University Press.

Rosen, Y., & Beck-Hill, D. (2012). Intertwining digital content and a one-to-one laptop environment in teaching and learning: Lessons from the time to know program. *Journal of Research on Technology in Education*, *44*(3), 225–241. https://doi.org/10.1080/15391523.2012.10782588

Schuetz, R. L., Biancarosa, G., & Goode, J. (2018) Is technology the answer? Investigating students' engagement in math. *Journal of Research on Technology in Education, 50*(4), 318–332. https://doi.org/10.1080/15391523.2018.1490937

Selwyn, N. (2021). Ed-Tech Within Limits: anticipating educational technology in times of environmental crisis. E-Learning and Digital Media

Selwyn, N. (2012). *Education in a digital world: Global perspectives on technology and education*. Routledge.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. http://dx.doi.org/10.3102/0013189X015002004

Somekh, B. (2007). *Pedagogy and learning with ICT: Researching the art of innovation.* Routledge.

Subramaniam, K. (2007). Teachers' mindsets and the integration of computer technology. *British Journal of Educational Technology*, *38*(6), 1056–1071. https://doi.org/10.1111/j.1467-8535.2006.00693.x

Trucano, M. (2017, November 6). *20 innovative edtech projects from around the world.* World Bank. Retrieved January 27, 2023, from https://blogs.worldbank.org/edutech/20-innovative-edtech-projects-around-world

Trucano, M., & Dykes, G. (2017). Lessons from international experiences. In M. Trucano & G. Dykes (Eds.), *Building and sustaining national educational technology agencies. Lessons, models and case studies from around the world* (pp. 1–31). The World Bank. https://openknowledge.worldbank.org/handle/10986/26507

Turgut, G. (2013). International tests and the U.S. educational reforms: Can success be replicated? *The Clearing House*, *86*(2), 64–73. https://www.jstor.org/stable/43999319

UNESCO Institute of Statistics (2017). International standard classification for education. http://isced.uis.unesco.org/

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge – A review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109–121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Warschauer, M., Knobel, M., & Stone, L. (2004). Technology and equity in schooling: Deconstructing the digital divide. *Educational Policy*, *18*(4), 562-588.

Warschauer, M., Zheng, B., Niiya, M., Cotten, S., & Farkas, G. (2014). Balancing the one-to-one equation: Equity and access in three laptop programs. *Equity & Excellence in Education*, *47*(1), 46–62. https://doi.org/10.1080/10665684.2014.866871

Whipp, J. L., Eckman, E. W., & van den Kieboom, L. (2005). Using sociocultural theory to guide teacher use and integration of instructional technology in two professional development schools. *Journal of Computing in Teacher Education, 22*(1), 37–43. https://www.tandfonline.com/doi/abs/10.1080/10402454.2005.10784534

Willis, R., Lynch, D., Fradale, P., & Yeigh, T. (2019). Influences on purposeful implementation of ICT into the classroom: An exploratory study of K-12 teachers. *Education and Information Technologies*, *24*(1), 63–77. https://doi.org/10.1007/s10639-018-9760-0

Willis, R., Yeigh, T., Lynch, D., Smith, R., Provost, S., Sell, K., & Turner, D. (2018). *Towards a strategic blend in education: A review of the blended learning literature.* Oxford Global Press.

Wilson, M. L., Ritzhaupt, A. D., Cheng, L. (2020). The impact of teacher education courses for technology integration on pre-service teacher knowledge: A meta-analysis study. *Computers & Education*, 156, Article 103941. https://doi.org/10.1016/j.compedu.2020.103941

World Bank. (2016). World Bank open data. Retrieved from http://data.worldbank.org

Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for classroom technology innovations. *Teachers College Record*, *104*(3), 482–485. https://doi.org/10.1111/1467-9620.001