# TEACHER PROFESSIONAL DEVELOPMENT FOR THE DIGITAL AGE: MAKING TECHNOLOGY INTEGRATION POSSIBLE

A Dissertation

by

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# ABSTRACT

In this dissertation study, I have examined the relationship between teacher PD, teacher use of technology and student achievement. In the first article, I evaluated the effect of teacher PD which uses technology on student achievement. Using robust variance estimates and meta-analytic techniques, I synthesized evidence from 7 articles (20 studies), and found the effect of technology blended PD on student achievement to be 0.174 ($p<.001$). Moderator analysis confirmed that student achievement was impacted when technology in PD was used for surface level features to teach teachers, but not to construct new knowledge. In the second study, I use secondary data from a large national database (TALIS), to build a multilevel model and examine the effect of technology in PD on classroom use of technology. Using ordinal logistic regression, I found evidence to suggest that technology use in PD has a negative impact on classroom technology use. The third article is a mixed-methods study, in which I use longitudinal data to understand the effect of a technology-rich PD on teachers' perceptions of barriers to technology use. The findings from the third study revealed that there was no significant difference between pre and post program perceptions of teachers, and that the PD did not help them make connections between what they learned in the PD and the content they needed to teach. Implications for each study are discussed separately, and then synthesized and discussed together in the concluding chapter.

## DEDICATION

This dissertation is dedicated to Mrs Mitali Mukerji, my mother, and Mrs Geeta Chatterji (deceased), my grandmother, the two women whose unfailing strength and wisdom gave me courage to embark on and complete this journey.

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# CONTRIBUTORS AND FUNDING SOURCES

## Contributors

This work was supervised by a dissertation committee consisting of Professor Hersh Waxman and Professors Trina Davis and Debra McKeown of the Department of Teaching, Learning and Culture and Professor Jennifer Whitfield of the Department of Mathematics.

The data analysis in Chapter 1 was overseen by Dr Christopher Thompson. The data analyzed in Chapter 3 was provided in part by Professor Trina Davis.

All other work conducted for the dissertation was completed by the student independently.

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## NOMENCLATURE

| | |
|---|---|
| PD | Professional Development |
| BL | Blended Learning |
| ICT | Information Communication Technology |
| SECURE | Secure Teacher Education by Utilizing Research Experiences |
| RET | Research Experience for Teachers |
| NSF | National Science Foundation |
| OECD | Organization for Economic Co-operation and Development |
| TALIS | Teaching and Learning International Survey |

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# INTRODUCTION

Effective teaching practices are a principal determining factor of student learning. There is evidence to suggest approximately 30% of student achievement is a result of teachers' instructional practices (Creemers, Kyriakides, & Antoniou, 2012; Hattie, 2012). Researchers have acknowledged the power of computer-mediated learning environments for teaching and learning, and evidence from prior research shows small to medium scale effects on student learning with the use of technology (Allen et al., 2011; Cheung & Slavin, 2012, 2013; Fernández-Gutiérrez et al., 2020; Salvin, Lake & Groff, 2009; Tamim et al., 2011, Xu et al., 2019a, 2019b). However, teaching effectively with technology is dependent on how it is integrated into regular classroom instruction (European Commission, 2013; Heitink, Voogt, Verplanken, van Braak & Fisser, 2016; Mishra & Koehler, 2006; Webb & Cox, 2004). There is evidence to suggest that effective technology integration is closely linked to learner-centered classrooms (Tondeur et al., 2013; Pareja Roblin et al., 2018). Additionally, several researchers have reported that teachers can find value in technology use when it is aligned with their current instructional practices (Lim and Chan 2007; Tondeur et al. 2013). In fact, Tondeur et al. (2008) suggest that technology use can benefit teachers in their classrooms as an effective instructional tool. In order to improve the impact of technology in K-12 classrooms, it is therefore important to understand the factors that influence technology-rich teaching practices, and how to implement such practices in a classroom.

Research studies have established a strong link between teachers' knowledge and beliefs, their thought processes, and their general ability to teach (Cohen & Ball, 1990; Shulman, 1987; Woodbury & Gess-Newsome, 2002). In particular, how teachers employ computer-mediated teaching and learning techniques is determined by educational factors, like their own knowledge of the technology, formal training, personal and pedagogical beliefs, and instructional practices (Heitink et al., 2016; Tondeur et al., 2016). Despite the importance of technology integration in the classroom, teachers often fall short of effectively using it for teaching and learning (Blanchard et al., 2016; Fishman et al, 2004; Niederhauser et al., 2018). Some researchers have asserted that most teachers do not have adequate professional development (PD) to  aid them in transformative use of technology in the classroom (Hew & Brush, 2007; Ryan & Bagley, 2015), and that there is a lack of directed efforts to improve teachers' technology use in the classroom (Vongkulluksn, Xie, & Bowman, 2018). Therefore, while teachers use technology for general purposes, they do not seem to be integrating it into their content to impact student learning.

To develop an understanding of how teacher professional development (PD) can influence knowledge and technology use by teachers, it is necessary to gain insight into connections between formal teacher PD in technology integration and how it influences classroom use. Through three separate articles, the current dissertation focuses on the role of teacher PD in technology use and how such PD impacts student achievement, classroom use of technology, and teacher perceptions of obstacles to technology use.

**Teacher Professional Development (PD)**

Teacher PD is a recognized mode of teacher education for in-service teachers to continue to grow in their pedagogical and content knowledge (Guskey, 2000, 2002); and an effective PD program should result in measurable changes in teachers' cognitive, behavioral, and affective domains (Guskey, 2002). Much of the literature on effective PD practices has established that effective PD is critical to improving teaching quality and closing student achievement gaps (Darling-Hammond et al., 2009; Heller et al, 2012; Hill, Beisegel & Jacob, 2013; Kennedy, 2016; Yoon et al., 2007). Although there is recognition of the positive effects of PD, researchers and stakeholders are rarely in consensus on the features of effective PD (e.g., content focus, active learning, and duration)(Darling-Hammond & Richardson, 2009; Wilson, 2009).Therefore, while there is a considerable increase in the number of PD programs offered to teachers, PD facilitators' understanding of key characteristics of such PD programs has not improved accordingly (Blank et al., 2008; Garet et al., 2011; Garet et al., 2016; Piasta, Logan, Pelatti, Capps, & Petrill, 2015; Santagata, Kersting, Givvin, & Stigler, 2011). The important role of identifying core components of PD programs, and how they improve teachers' knowledge and skills has been performed by a few large-scale empirical research studies (e.g., Desimone et al., 2002; Garet et al., 2001; Supovitz & Turner, 2000). However, there is a paucity of research linking teacher professional development, instructional practices, teacher beliefs and attitudes to student learning outcomes (Capps, Crawford, & Constas, 2012; Guskey & Yoon, 2009; Hill, Beisiegal, & Jacob, 2013). Guskey and Yoon (2009) have called for additional research that elucidates the impact teacher PD has on student achievement.  Collectively, these studies indicate the important role of PD in teacher learning, but they also call for further research into this field.

**Technology Enhanced Teacher PD/ Blended PD**

Most in-service teachers have had limited experiences in learning technology integration for classroom instruction (Fishman et al., 2004). Hew and Brush (2007) suggest that most teachers do not have adequate PD that helps in using technology for transformative learning; PD usually trains them to use technology within familiar models of instructional practices. However, when teachers perceive technology enhanced PD as ineffective, it is less likely that they will integrate that particular technology into their instructional practices (Lawless & Pellegrino, 2007; Potter & Rockinson-Szapkiw, 2012). It is critical to ensure technology training for teachers through PD programs assist teachers in becoming familiar with new methods to integrate technology into their content areas, and adapt instructional practices to fit the needs of diverse learners (Fernandes, Rodrigues, & Ferreira, 2018; Lawless and Pellegrino, 2007). Therefore, researchers have suggested that technology enhanced PD programs need to be developed to help teachers learn how to integrate technology into their content and transform their instructional practices.

Scholars and researchers have also used the terms blended learning (Spanjers et al., 2015) and hybrid learning (Raes et al., 2020) to describe technology enhanced learning. In essence, this type of learning is characterized by face-to-face learning which is complemented by computer mediated learning. In the current proposal, the term blended learning will be used for the first article.

**Technology Integration**

Although many schools continuously work towards integrating instructional technology tools, like interactive whiteboard, mobile learning environments, Moodle platform, computers/laptops, and software like simulation, the Internet or Web, multimedia and hypermedia, animation, games, wiki resources, educational software, videoconferencing and so on (Fernandes, Rodrigues, & Ferreira, 2018), most teachers' instructional practices remain fundamentally unchanged, and they did not use newer technology (Sancho, 2010; Sancho-Gil, Rivera-Vargas, & Miño-Puigcercós, 2020). Researchers have asserted that teachers' failure to use technology for more than administrative purposes and traditional instruction is due to a lack of confidence with technology (Lee, Longhurst & Campbell, 2017; Lussier, Gomez, Hurst, & Hendrick, 2007; Zhao & Cziko, 2001) or a lack of supportive PD (Baylor & Ritchie, 2002; Li, Garza, Keicher, & Popov, 2019; Ping Lim & Sing Chai, 2008). All of the studies reviewed here support the hypothesis that technology integration is not taking place as desired, and teachers need more training to accomplish that goal.

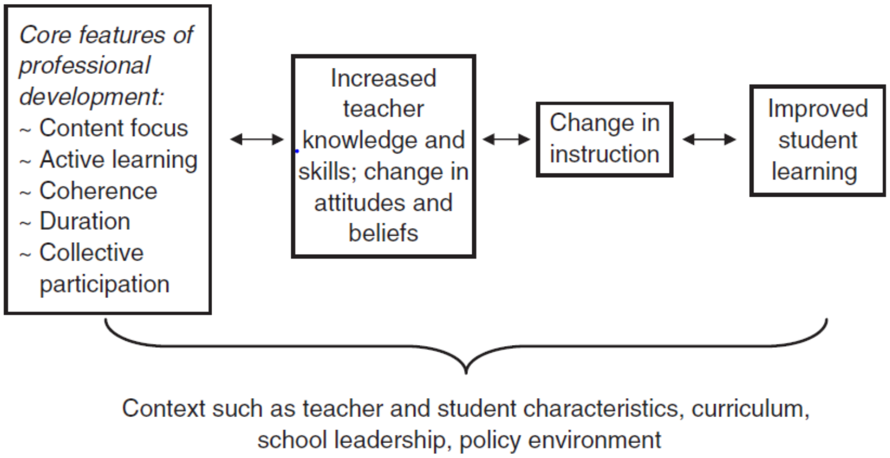
### Technology Resources for Classrooms

To further complicate the issue, there are a wide range of digital resources or technology tools available to teachers today. Teachers may have access to hardware like the ones mentioned earlier; however, in many cases, these resources are bundled together and termed Information Communication Technology (ICT) (OECD, 2018). Many scholars chose to study how ICT is implemented in classrooms in general instead of parsing out its many components the many components of ICT (Gil-Flores, 2017; Tondeur, 2018; Scherer, Siddiq, & Tondeur, 2019) while others chose to study the impact of one type of technology and how it is used. Some examples of technologies studied are one-to-one laptops (Lei & Zhao, 2008; Zheng et al., 2016), computer games (Brom et al., 2011; Terras & Boyle, 2019; Tsai et al., 2020), interactive whiteboards (Cheng et al, 2020; Wong et al., 2013), Ipads (Diacopoulos & Crompton, 2020; Crompton & Burke, 2018), and so on.  There are currently a myriad of technological tools and resources being used in schools, and more are being introduced every year.

## Theoretical Perspective

The overarching theoretical perspective for the current proposal is situated on the key features of PD suggested by Desimone (2009). Educational researchers have frequently used Desimone's (2009) framework to establish critical features of PD programs. In her seminal paper, "Improving impact studies of teachers' professional development: Toward better conceptualizations and measures.", Desimone (2009) has suggested five core features of teacher PD by reviewing previously existing literature. The five critical features of an effective PD program are content focus, active learning, coherence, duration, and collective participation. Figure 1 depicts the theoretical framework of Desimone (2009).

**Figure 1.** *Core features of PD programs (Desimone, 2009)*




As the term implies, "content focus" is the emphasis on subject, or content knowledge. "Active learning" refers to instruction that is student centered. In the case of teachers, learning is encouraged through different activities like observations, interactions, discussions, and giving feedback to students and each other. The third dimension of effective teacher PD is "coherence", which implies the PD should be compatible with the beliefs and knowledge of the teachers, and that it should present the content and pedagogy that is required by State and school policies and standards. The fourth factor in effective PD is "duration," which signifies the length and intensity of the PD program. While there is evidence to suggest that PD programs of longer duration may be more effective, there is little consensus on what the exact duration of such PD should be. The final component of effective PD program is "collective participation". As the term suggests, "collective participation" signals collaboration and interaction among the participants of the PD program. Measurement of effectiveness within the paradigm of these five critical features should enable researchers to establish consistency in their findings.

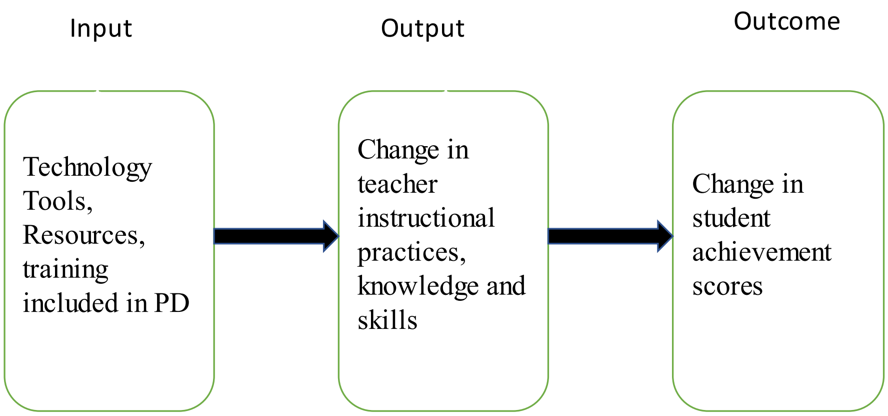
## Theory of Change

The proposed theory of change for the current paper is adapted from Desimone (2009). With this theory of change, I hope to map out short-term and medium-term outcomes for domains of teacher growth. The distal goal to achieve is the changes in affective domain (for example, knowledge and skills), which are preceded by changes in behavioral (for example, instructional practices) and cognitive domain (for example, attitudes and beliefs) (Guskey, 2002).

The measure for the predicted change will show us the differences in the teacher instructional practices and knowledge as a result of technology use in PD. The three articles which follow in the current study are analyses of technology use in teacher PD and its impact on the three domains of teacher learning.  Figure 2 depicts the activities, output and outcome for the current study.

**Figure 2**

*Theory of Change (adapted from Desimone, 2009)*




## Purpose of Dissertation

The purpose of this three-article dissertation is to examine: (a) the causal link between technology enhanced PD and student achievement outcomes, (b) the impact of technology use in

PD on classroom use of technology, and (c) the impact of technology enhanced PD on teacher perceptions of challenges with technology use in classrooms. The overarching goal of the current study is to better understand how technology use in PD can contribute to technology integration in teachers' instructional practices. First, the study will include a meta-analysis, in which a general overall effect size will be generated for student achievement scores. The effects of specific types of technology use in PD will be evaluated using moderator analyses. In the second article, secondary data analysis from large scale national surveys will be analyzed to determine the impact of technology in PD on teachers' classroom use of technology. Finally, longitudinal survey data will be used to understand the shift in perceptions of challenges to technology integration in the classroom.

The current study is relevant to policymakers and teacher educators who would like to see improvement in student learning outcomes. The understanding of how technology enhanced PD impacts appropriate technology integration in the classroom can be used to develop targeted interventions. The findings from this research can provide insight into the perplexing area of technology enhanced teacher PD. As many teacher educators and policy makers try to steer teacher PD in an impactful direction, the current study can indicate what that direction might be.

## Method

In this dissertation proposal, I will provide an overview of three research studies which examine how student achievement, teacher instructional practices and teacher beliefs can be impacted by technology in teacher PD.  I will outline the research questions, setting, data sources, and procedures in the next section.

**Article One**

Proposed title: *Impact of Blended Learning in Teacher Professional Development on Student Achievement: A Meta-Analysis.*

**Research questions**

**1)** Is there a relationship between blended PD and student achievement?

**2)** How do study characteristics (e.g., experimental design, content area, grade level) moderate the effect of technology use in teacher PD on student achievement scores?

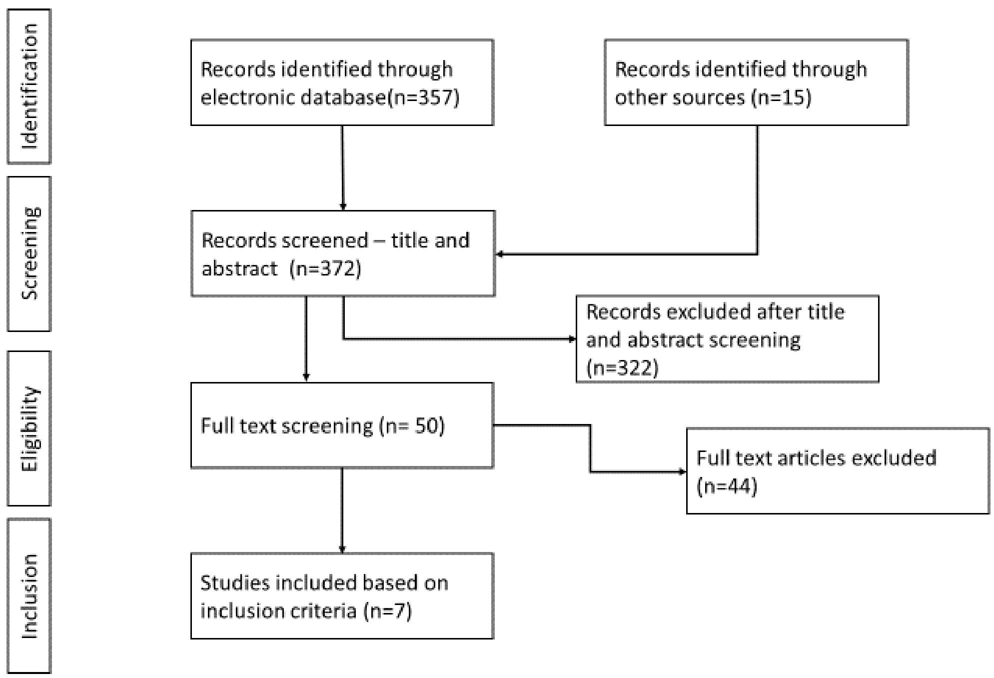
**3)** How do intervention characteristics (e.g., how technology was used, total number of hours, continuum into the academic year, fidelity of implementation) moderate the effect of technology use in teacher PD on student achievement scores?

**Search procedures**

Our database search included Eric, Education Source, ProQuest Dissertation and thesis, and Professional Development Collection. When our electronic searches were concluded, we began performing manual searches of relevant journals (*Teaching and Teacher Education, Journal of Teacher Education, Computers & Education, Journal of Research on Educational Effectiveness, Journal of Research in Science Teaching, American Education Research Journal, Educational Researcher, Journal of Teacher Education, Teaching and Teacher Education,* and *American Journal of Education*). We also searched the What Works Clearinghouse, Teacher Excellence section for relevant studies. Finally, the references from all included studies were analyzed and pertinent articles were located. We emailed authors of papers for when the articles could not be found online or through library resources. This method did not give us good results as most of the authors contacted did not respond to our queries.

The details of the key search terms used for the current study can be viewed in Appendix A. Our initial database search yielded 357 articles, and our hand search yielded 15 articles. After title and abstract screening, we were left with nine articles. Upon filtering the articles for full text, we were able to find six that provided us with the relevant information and data for our meta-analysis. The details of this process can be viewed in Figure 1.

**Figure 1.** *PRISMA Diagram: Search Process for Included Articles*




## Inclusion Exclusion Criteria

We used the following inclusion criteria for selecting the studies in the current analysis.

- The study must describe PD for teachers that has a technology element in it.
- The study must include student learning outcomes in the form of achievement scores.
- It must be quasi-experimental or experimental in design.
- All available literature was included -- peer reviewed and non-peer reviewed.

- Articles with preK-12 teachers from science and mathematics content areas were included.
- All national and international studies were included as long as they were in English.
- All studies conducted from 2000 to 2019 were included.
- Studies included contained the statistics necessary to calculate an effect size.

We excluded research that measured student achievement using technology but did not describe the technology component of the PD program. The studies that did not provide us with enough data for an effect size were excluded. For example, a study by Lowther, Inan, Daniel, and Ross (2008) met all the inclusion criteria except information on student achievement scores. Our attempts to contact the authors regarding the information were unsuccessful; therefore, we excluded the study from our analysis. Another study by the same authors was excluded because it lacked information on teacher training. Furthermore, we excluded studies that compared purely online environments to face-to-face learning. In essence, we included studies that gave us some description of how technology was used to enhance a traditional learning environment for teacher audiences.

**Coding Procedures**

The first author developed the coding scheme by reading the articles, and came up with 25 items for the coding scheme and then trained two researchers on the coding scheme. The study features included PD type, technology type, content area, grade level, sample size and so on. Three trained researchers then proceeded to code three (50%) randomly selected studies on an individual basis, and then came together to establish inter-rater reliability, which was established at 95%. The disagreement for the remaining 5% was resolved through discussion so the rest of the coding process could continue. Each coder then began coding on an individual basis; in the eventuality that one coder was unsure of her coding, she would consult the other two coders and the conflict was resolved as a group.

### Computing Effect Sizes

We calculated Hedge's *g* using the concept of standardized mean difference. The Hedge's *g* formula used in the current paper is presented in Figure 2.

**Figure 2.** *Hedge's g Formula*

The Hedge's g formula is:

$$\text{Hedges' } g = \frac{M_1 - M_2}{SD^*_{pooled}}$$

Means, standard deviations and sample size of treatment and control groups were inputted into a researcher created Excel worksheet; where more than one effect size for the same group of participants was reported, and the effect size was for a different lesson, or chapter, it was reported separately. For example, Myer (2009) reported effect sizes for different topics in mathematics (number sense, measurement, geometry, algebraic thinking, data analysis). Since each one of these units measures different skills, we reported an effect size for each of them. Therefore, the number of effect sizes for the current meta-analysis (74) is larger than the number of studies (7).

### Data Analysis

The current meta-analysis used robust variance estimation (RVE) technique to analyze the effect sizes. The RVE technique is justified in cases where there may be a correlation between standard errors of effect sizes. In other words, the assumption that the effect sizes in a cluster of studies are independent of each other is violated (Fisher & Tipton, 2015; Hedges, Tipton & Johnson, 2010). Standard errors for effect sizes are adjusted mathematically for dependency thought the RVE procedure (Tanner-Smith & Tipton, 2014; Tanner-Smith, Tipton, & Polanin, 2016). In the case of the current meta-analysis, since each study yields multiple effect sizes, we believe that the RVE method of analysis would yield more accurate results. For this purpose, we have used the R package "Robumeta" for the analysis (Fisher & Tipton, 2015).

## Article Two

**Proposed Title**: *Role of Teacher Professional Development in Classroom Technology Use: A Multilevel Analysis*

### RQs

1) What is the correlation between classroom ICT use, ICT in PD, and teacher characteristics (age, gender, experience, certification, formal preparation to teach with ICT, highest level of education, preparedness to teach using ICT)?
2) At the school level, how does ICT in PD predict classroom ICT use?
3) At the teacher level, how do teacher characteristics (age, gender, experience, certification, formal preparation to teach with ICT, highest level of education, preparedness to teach using ICT) predict classroom ICT use?

### Data Sources

The current study utilizes the data set obtained from TALIS 2018 teacher survey (OECD, 2018). The surveys were obtained from representative samples of teachers in the U.S. The TALIS questionnaire provides policy makers and researchers with factors that might be indicative of reforms that result in improvement in teaching and learning (OECD, 2018).

### Data Analysis

#### *Participants and Setting*

The participants were 7th through 9th grade teachers from U.S. schools. In terms of International Classification of Education, these are ISCED-2 level. This selection of grades is frequently referred to as lower secondary level.  There were 2,560 teachers nested in 165 schools in this sample.

### *Variables*

The dependent variable for the current study is ICT use in classrooms. ICT use is self-reported by teachers and is categorized into four distinct groups; “never or nearly never,” “occasionally,” “frequently,” or “in all or nearly all lessons.”. In a previous study, Gil-Flores, Rodríguez-Santero, and Torres-Gordillo (2017) used the same dependent variable but collapsed them into two categories, “users” and “non-users.” For the purpose of the current study, we will be utilizing the same process of collapsing the four categories into three.

We have used one independent variables for RQ1 in this study, grouped under three levels. The first independent variable is ICT professional development. The two categories of response for ICT professional development were “yes” or “no”.

The dependent variable for the current study is ICT use in classrooms. The dependent variable for the study was measured on a yes, sometimes, no categorical scale, with responses to the question on how often students used ICT for projects and classwork and were divided into 3 distinct categories (1 – never, 2- some, 3-all the time)

The current study uses five independent variables for RQ2. These are teacher characteristics – age, sex, experience, certification and subject taught.

### *Data Analysis Technique*

Since our dependent variable was dichotomous, we used binary logistic regression analysis as the main procedure for analysis in the current study. Additionally, since schools form clusters we analyzed the data using a two-level binary logistic regression. Correlational analysis among the variables was established before the logistic regression was conducted. Missing cases were excluded from the analysis.

Odds ratio are calculated using β coefficients. An odds ratio is a measure of association between a dependent and independent variable. This measure gives us the probability of the occurrence of an outcome depending on the predictor. In other words, it tells us the probability of a dependent event happening under exposure of an independent event. In the case of the current study, the probability of ICT use in a classroom depending on ICT PD and new technologies in ICT PD occurring.

**Article Three**

**Proposed Title:** *STEM Teachers Technology Integration Practices: Through the Lens of Complexity Theory*

**Research Questions:**

1. How do teacher perceptions of external barriers to technology use change as a result of a Research Experience for Teachers (RET) PD?
2. What common themes emerge after the completion of RET PD?

**Data Sources**

***Participants and setting***

The six-week professional development was held on campus in a large public university in Central Texas. The participants were teachers who currently taught in local area middle schools, high schools and community colleges, and were recruited via the program website and through email. For each year of the study, emails were sent to local area schools and community colleges to seek out interested teachers. The participating teachers were paid a $7,500 stipend for their participation in the program. Teachers who taught mathematics, computer science, career and technical education (CTE) or STEM subjects at the post-secondary level were given preference, but there was no rule to exclude other content areas. Selected participants taught a variety of STEM subjects (e.g., mathematics, engineering, computer science, robotics, technology. Each year, there was space for ten teachers to participate in the project. However, since the funding for the project was approved at a late date, there were only 9 teachers recruited the first year, 2017. Similarly, there were 9 teachers recruited during year 3, 2019. Each year two of the participants from the previous year were asked to participate in the PD. Therefore, while there are 28 teachers in the sample, the responses of 24 participants are analyzed in this study.

### *Program Description*

In the intensive six-week Research Experience for Teachers (RET) Program participants were provided with structured research experience in a university laboratory while working with faculty mentors, their graduate students and other related research groups (NSF, 2012). In these settings, participating teachers learn to work on research activities and projects. Additionally, teachers were provided opportunities to participate in community activities, and professional sessions with industry partners from STEM professions, like technology and manufacturing companies.

### *Procedures*

All participants were emailed the pre-survey before they attended the first day of the PD. The facilitators of the PD program also assigned a time period of approximately 10-15 minutes for the participants to complete the pre-survey before the commencement of the PD program. A researcher was present at this time to answer questions about the survey, if any arose.

During the last day of the PD program, approximately 15-20 minutes was once again set aside by the facilitators for the participants to complete their post-surveys. Again, a researcher was present on the premises to answer any questions or concerns regarding the survey. This process of administration was repeated every year for each cohort.

The participants also wrote and submitted a one-page reflection on how they would connect their RET learning with their classroom instruction. The reflections were completed before or immediately after the post survey was administered. In other words, the data for the post survey and the reflection were collected almost concurrently.

### *Survey Instrument*

The survey instrument was adapted from a SRI International survey which was developed to examine NSF supported research experience for undergraduate students (Russell, 2006). The adapted pre-survey contained 48 items, of which 45 were ordinal or categorical, and the rest were open-ended. The post survey contained 50 ordinal or categorical items, and 5 open-ended responses. Both the pre and post surveys were divided into several sections, each measuring a different construct. Detailed information on the individual sections is provided below. The survey questions are reported in Appendix B.

***Teacher and student information (pre-survey only).*** The survey opened with a section on teacher information. This section had 19 questions and asked teachers their names, age, ethnicity, their grade levels, subject areas taught, type of school they taught in, location of the school. Teachers were asked about how long they had taught, their highest level of educational qualification, and the subject in which they received their highest degree. It also asked the participants about the composition of their student body like the percentage of students who were eligible for free and reduced lunches, percentage of students who had internet access at home.

***Impact of RET program on awareness of aspects of STEM teaching.*** In this section, teachers were asked to estimate the effect of the RE RET on their awareness of various technological resources and tools, STEM issues, STEM career options, general knowledge base in STEM pre and post the intervention. A 4-point Likert scale was used to answer the 6 questions in this section, 1 being None, and 4 being A lot. Cronbach’s alpha was measured at 0.95.

***Impact of RET experiences STEM teaching.*** All items loaded into one factor and Cronbach’s alpha was established at 9.48.

***Impact of RET program on STEM attitudes and beliefs.*** There were 5 items in this construct, asking teachers about their ability, confidence, motivation and skill in teaching with technology in their classrooms. Teachers selected from a 5-point Likert scale with 1 being None, and 5 being Have no idea.

***RET program influence on Research Practices.*** This section had five questions and was dedicated to understanding the teachers’ perceptions of the RET experiences, both before and after the intervention had taken place, and how it had changed their perceptions of STEM research practices. It contained questions like RET and understanding research practices, scientific knowledge, applications of STEM, ethical dimensions of STEM and so on.

***RET program logistic experiences.*** In this section, the participants were asked how well the basic logistics of the RET coordinating team worked for them. The questions in this section included information on information about the program, contact with the program manager, scheduling, program logistics and so on. There were seven questions in this section.

***Satisfaction with program (post survey).*** In order to understand how to better serve the participants, this section had 20 questions included questions about interactions with mentors, faculty, graduate students, as well as satisfaction with the stipend. It also asked participants how satisfied they were with how they were able to transfer the knowledge gained from the PD program to their classrooms.

***Challenges to technology integration.*** The participants were asked to identify external challenges that they might find when trying to teach what they had learned. This section therefore included questions like lack of computers and internet, lack of time, lack of admirative support and so on. Teachers were asked to select each obstacle they felt they might face in integrating technology into their classrooms. The choices were therefore dichotomous, in which each individual teacher selected as many obstacles he/she felt were applicable to him/her, while leaving the others unselected.

***Open-ended questions (pre survey).*** This pre survey had three open-ended questions asking the participants to write more about the challenges they thought they might have to face, why they joined the PD program and how they thought it might help their classroom instruction. The same section in the post survey had

***Open-ended questions (post survey).*** There were five open-ended questions in this section, about the best aspects of the program, suggestions for improvements, comparing with other professional development programs, integrating the RET into the classroom, and possible difficulties in integration.

**Data Analysis**

For the purposes of the current study, I have employed a mixed-methods approach to data collection and analysis. Mixed methods is defined by Johnson, Onwuegbuzie & Turner (2007) as "….. the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration." (p 123).

A mixed methods technique is suitable for the current study because through mixing of qualitative and quantitative data triangulation can be achieved. Triangulation is an important element in mixed methods as it can confirm or corroborate one source of data with another. Another reason is combining two types of data analyses can help the researcher develop richer and more meaningful conclusions. (Rossman & Wilson, 1985). Therefore, mixed methods may provide a richer and deeper understanding of the answers to the research questions.

The type of design used for the current study has been termed convergent (or concurrent) design by Creswell and Clark (2018). In this design, qualitative and quantitative data are collected and analyzed simultaneously. The main purpose of this research design is to triangulate qualitative results with the aid of quantitative data analysis. The qualitative data provided the participants perceptions of the interaction of these key variables, and the quantitative data in the current study provided the researchers with the important variables for the analysis.

### *Analysis of Qualitative Data*

For the current study, we used qualitative analysis to detect the common themes across teachers and administrators. Two trained researchers read and analyzed one-third of the open-ended responses and the reflection documents. They determined important themes in the documents inductively, and then came together to determine inter-rater reliability. Inter-rater reliability was established at 85%. The first researcher then coded the remaining reflections using the categories developed inductively.

### *Analysis of Quantitative Data*

We used the quantitative data to support our findings from our quantitative data analysis. We analyzed quantitative data using descriptive statistics, mean/standard deviations and percentages. The means and standard deviations of each cohort as well as the cumulative means and standard deviations from the pre survey were calculated and recorded. A McNemarr test for group differences for non-normal binary data distributions were carried out, and results were reported.

## Conclusion

In this dissertation, the first article, a meta-analysis aims to synthesize empirical evidence that technology use in STEM teacher PD results in higher student achievement scores. Additionally, the characteristics comprising of the way technology is used, fidelity of implementation, continued support for teachers and PD duration are studied; and their impact on student achievement are investigated. Some other characteristics such as study design, content area, and grade level are examined as moderators of student achievement scores. The first article therefore, provides the foundation for the other two studies by establishing that technology enhanced PD is significantly better than non-technology PD.

The second article utilizes a large-scale national survey data from OECD (2018), and attempts to find evidence to support the hypothesis that technology use in a STEM teacher PD increases technology use in the classroom. In addition, predictors of technology use such as teachers' characteristics (e.g., age, experience, certification), and content area taught is analyzed using multi-level logistic regression techniques. The second study therefore, provides an analysis of how technology enhanced PD might predict classroom use of technology.

The third article examines the perceptions of obstacles to technology use in three cohorts of STEM teachers who attended a Research Experience for Teachers (RET) PD. This mixed methods study takes longitudinal data (collected over 3 years) from 24 participants, and examines changes to teacher perceptions to obstacles to technology use pre- and post-PD. This study utilizes a mixed methods approach to comprehend how a technology enhanced PD can induce changes in teacher perceptions about technology use in the classroom.

Collectively, these three studies make a significant contribution to the field of teacher PD because they provide a deeper understanding of the factors that affect the use of technology in the classroom. Not only does this dissertation synthesize evidence of positive impact of technology use in PD on student achievement, it also analyzes predictors of technology use in the classroom, and examines the changes in teacher perceptions of obstacles to technology use as a result of a technology enhanced PD. These three studies provide an understanding of technology integration in STEM teacher PD, and expands on the knowledge base of researchers committed to conceptualizing effective PD programs.

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## IMPACT OF BLENDED LEARNING IN TEACHER PROFESSIONAL DEVELOPMENT ON STUDENT LEARNING: A META-ANALYSIS

Blended learning (BL) is a teaching technique utilized to enhance student learning experiences and outcomes, and is defined as a mix of face-to-face and online learning (Graham, 2013). BL has gained popularity over the years and many researchers are pursuing ways and means to define and develop effective instructional practices in BL environments (Halverson et al., 2014; Halverson et al., 2017). However, Rasheed et al., (2020) have pointed out that most of the literature on BL is focused on challenges faced by students, rather than those faced by teachers. Unsurprisingly, there is a paucity of research in BL in teacher professional development (PD) as well as how BL in teacher PD impacts student achievement (Yoon et al., 2007). Approximately 7% of the studies in BL address teacher PD (Drysdale et al., 2013). Therefore, there is a lack of systematic understanding of the effect of BL on teacher learning and student achievement. Additionally, there is scant research on how BL used in teacher PD influences student achievement. The current meta-analysis therefore, seeks to examine the evidence of effect of BL in teacher PD and its impact on student achievement. This study also seeks to investigate the manner in which technology use in teacher PD catalyzes student learning. By synthesizing the research outcomes on what is currently known about BL and how technologies are used in BL teacher PD, this meta-analysis makes an important contribution for decision makers such as teacher educators and policy makers.

The current meta-analysis adds to the current knowledge base in three important ways. First, the current meta-analysis is limited to studies from 2000 to 2020 because computer-mediated learning environments have evolved greatly in the last two decades (Spanjers et al., 2015). Additionally, previous meta-analyses have not focused on *how* technology is used in BL learning environments. The current meta-analysis uses the ACI (Active, Constructive, Interactive) framework (Chi, 2009) to examine the *how* technology is used in the BL environment. Third, and most importantly, this study captures the impact of BL teacher PD on student learning, an outcome not addressed in previously published meta-analyses.

**Brief Review of Literature**

Much of the recent literature in BL focuses on challenges to technology integration by students more often than teachers (Rasheed et al., 2020). One such systematic review on the challenges of BL by Boelen's et al., (2017) found evidence to suggest that technology integration in BL was done only at the surface level, during introductory sessions, and that most students did not utilize the technology to the full extent. Additionally, an emphasis on differentiated learning was found in very few studies. However, BL seemed to be effective in monitoring student progress. A systematic review by Phillipsen et al., (2019) examined important elements of online and blended PD and why they were important. They found that PD duration, context, teacher reflections on the PD, and having the teachers evaluate the positive impact of PD were important components of such PD programs. Additionally, establishing a link between PD and student learning was also important. Neither of the above reviews focused on teachers or teacher PD.

Recent reviews that have focused on teacher learning are discussed in the section below. In a systematic review, Gamage and Tanwar (2017) looked for evidence of effectiveness of teacher training strategies that impacted technology use. The key to the success of the strategies seemed to lie with the teachers' acceptance of the technology or strategy. Teachers' perceived usefulness of technology was found to be twice as important as perceived ease of use, and facilitating teachers to use technology had a positive impact on its effective use. In the same vein, Rasheed et al., (2020) found evidence from 30 studies that negative perceptions of teachers on technology use, and lack of training, impact technology use.

In addition to these systematic reviews, the effect of BL or blended and computer mediated learning on learning outcomes and student satisfaction has been examined in six recent meta-analyses: Bernard et al. (2014); Means et al., (2013); Schmid et al. (2014); Spanjers et al., (2015) and Tamim et al., (2011). These meta-analyses found small to medium positive effects for student learning outcomes. Sitzmann et al. (2006) found a medium effect on procedural knowledge based on a small sample size (six studies). Results were less consistent for student satisfaction and reactions. The effect sizes of the meta-analyses can be viewed in Table 1. It should be noted that none of these recent meta-analyses address BL in teacher PD.

**Table 1**

*Average Effect Sizes for Recent Meta-analyses of BL on Student Achievement (adapted from Spanjers et al., 2015).*

| **First author, date** | **Participants** | **Average effect size** |
|---|---|---|
| Bernard et al., 2014 | Higher education | +0.35 *(student achievement)* |
| Means et al., 2013 | Higher education and secondary education | +0.35 (*student achievement*) |
| Tamim et al., 2011 | Primary, Elementary, Postsecondary | +0.33 (*student achievement*) |
| Schmid et al., 2014 | Postsecondary | +0.27*(student achievement)* |
| Spanjers et al., 2015 | Higher education | -0.01*(average of objective measures, subjective measures, satisfaction, investment evaluations)* |
| Vo et al., 2017 | Higher education | +0.385 *(student achievement)* |

**Theoretical Perspective**

For this meta-analysis, we use the theoretical framework for learning activities developed by Chi (2009) which differentiates learning activities on three levels – active, constructive, and interactive. We used this framework to develop the structure of our coding scheme. We used this theory to guide our coding scheme because we were interested in exploring the use of technology in teacher PD. This theory separates the different uses of technology based on its cognitive use. Active learning signals the performance of an activity while learning. An example of active learning in a computer mediated environment is searching, underlining, summarizing, selecting, copying and pasting (Chi, 2009). Constructive learning takes place when students generate a product of new information. In online learning, creating new information from previously established information is practiced by making concept maps, comparing and contrasting, making analogies, writing reflections, and so forth (Chi, 2009). The third level of learning, interactive, has been described as dialogues between teacher and student or between peers. In the case of computer-based learning, interactive learning is generally experienced through intelligent tutoring systems, and thus involves a tutor. Hence, through the use of the active-constructive-interactive framework, we differentiate the use of education technology used in teacher PD programs. We incorporate this framework to understand how one level of activity might have a different impact on student outcome as compared to other levels.

**Purpose of the study**

The impact of math, science and reading PD has been synthesized in the past few years (e.g., Blank & Alas, 2009; Didion et al., 2020), but there are not studies that synthesize the evidence from blended PD programs and how they impact student achievement. There has been an increase in studies that examine the effects of PD on student outcomes. Therefore, there is a need review evidence of blended PD on student achievement. Additionally, there are no syntheses on how technology use in PD can impact student outcomes. Therefore, it is the purpose of this study to examine the impact of blended PD on student outcomes, and to examine study characteristics and intervention characteristics as moderators of student achievement.

## Research Questions

**RQ1:** What is the relationship between blended learning professional development and PreK-12 student achievement in mathematics and science?

**RQ2:** How do study characteristics (i.e., study design, grade level, content area, outcome measures) moderate the effect of blended PD on student achievement?

**RQ3:** How do intervention characteristics (i.e., *how* technology was used in PD, implementation supports offered to teachers through the school year, PD intensity, fidelity of implementation) moderate the effect of blended PD on student achievement?

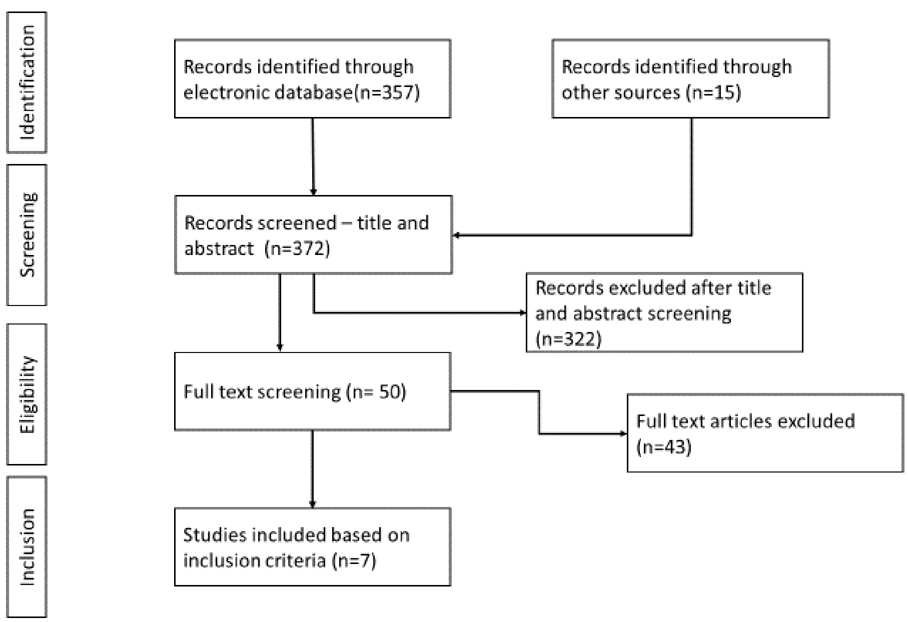
## Method

### *Search Procedures*

Our database search included Eric, Education Source, ProQuest Dissertation and thesis, and Professional Development Collection. We also performed manual searches of relevant journals (*Teaching and Teacher Education, Journal of Teacher Education, Computers & Education, Journal of Research on Educational Effectiveness, Journal of Research in Science Teaching, American Education Research Journal, Educational Researcher, Journal of Teacher Education, Teaching and Teacher Education,* and *American Journal of Education*). We also searched the What Works Clearinghouse, Teacher Excellence section for relevant studies. Finally, the references from all included studies were analyzed and pertinent articles were located. We emailed authors when the articles could not be found online or through library resources, but most of the authors contacted did not respond to our queries. Appendix A contains the search terms utilized in this meta-analysis.

Our initial database search yielded 357 articles, and our hand search yielded 15 articles. After title and abstract screening, we were left with nine articles. Upon filtering the articles for full text, we were able to find seven that provided us with the relevant information and data analysis. The details of this process can be viewed in Figure 1.

**Figure 1.**
*Prisma Diagram*




### *Inclusion and Exclusion Criteria*

We used the following inclusion criteria for selecting the studies in the current analysis: (a) must include PD for teachers that utilizes a blended learning model, (b) must describe both the PD and the technology element(s) used for blended learning, (c) The study must include student achievement scores in math or science, (d) PD was provided to teachers of Pre-K to 12, (e) teachers included taught math and/or science, (f) be quasi-experimental or experimental in design, (g) published in English, (h) be published between 2000 to 2020, and (i) contain the data needed to calculate an effect size. Studies were included regardless if they were peer reviewed or their geographical location.

We made attempts to contact researchers to obtain needed missing raw data, but did not succeed (*n*=3). Furthermore, we excluded studies that compared purely online environments to face-to-face learning, because our intentions were to examine a BL environment, which requires a component of face-to-face learning as well as online learning. In essence, we included studies that gave us some description of how technology was used for blended learning to enhance a traditional learning environment for teacher audiences.

***Coding Procedures***

The first author developed the coding scheme by identifying demographic codes and developing codes relating to the theoretical framework. The study features were coded for study characteristics and intervention characters (see Table 1 for details). The first author trained two researchers on the coding scheme. Agreement during training was 85%. Each researcher coded three (50%) randomly selected studies individually (inter-rater reliability was 95%). Disagreements were resolved through discussion and final agreement was 100%. See Table 2 for codes and definitions of moderators.

**Table 2**

*Codes and Definitions for Study and Intervention Characteristics (n=7, k=20, #ES=77)*

| Moderators | Code | Definition | *k* | #ES |
|---|---|---|---|---|
| Study design | RCT=1 | RCT – Random Control Trial | 7 | 21 |
| | QED=2 | QED – Quasi Experimental design | 13 | 56 |
| Grade level | Primary=1 | Primary – PreK | 4 | 22 |
| | Elementary=2 | Elementary – K-6 | 12 | 44 |
| | Secondary=3 | Secondary 7-12 | 4 | 10 |
| Content area | Math=1 | Content area taught and assessed | 14 | 64 |
| | Science =2 | | 6 | 13 |
| Outcome measures | Standardized = 1 | Measures used to assess the impact of the intervention. Measures designed | 3 | 7 |
| | Researcher designed=2 | by researchers; the outcome measure is researcher designed. District/State | 17 | 70 |

| | | | | |
|---|---|---|---|---|
| | | test is standardized. | | |
| Technology use in PD | Active=1<br>Constructive=2<br>Interactive=3 | Active – learn to use technology<br>Constructive – analyze and synthesize knowledge from technology<br>Interactive – technology interacts with teacher to construct knowledge | 15<br>5<br>0 | 52<br>25<br>0 |
| PD duration in hours | >24 hours = 1<br>1-23 hours =2 | Each day of PD was equivalent to 6 hours. Total time was calculated by adding together the days and hours spent in PD. | 18<br>2 | 65<br>12 |
| Implementation Support | Yes=1<br>No=2 | PD supports offered through school year, either online or face-to-face | 15<br>5 | 63<br>15 |
| FOI | Reported as high=1<br>Reported as low=2<br>Not reported/ not specified as low or high=3 | Fidelity of Implementation: The degree to which an intervention is delivered as intended. Level of FOI is reported as specified by the researchers of the specific study. | 5<br>1<br>14 | 15<br>1<br>60 |

### ***Computing effect sizes***

We calculated Hedge's *g* using the concept of standardized mean difference (Hedges, 1981). $\tau^2$ was calculated at $\rho$=0.80, and sensitivity analysis at $\rho$=0.20 to $\rho$=0.80 showed that our findings were robust across estimates. We chose $p$<.05 as our alpha value for estimating effect that are significantly different from zero. See Table 2 for included studies and effect sizes.

### ***Meta-analytic procedures***

For statistical analysis of dependent effect sizes in our meta-analysis, we used robust variance estimates (RVE) to estimate the effect sizes. This approach integrates multiple correlated effect sizes within a study instead of using one single effect size or calculating their averages (Hedges, Tipton, & Johnson, 2010; Tanner-Smith & Tipton, 2014). In this way, we have accounted for correlated effect sizes that may arise if the included studies are from the same research team, laboratory, or publication. First, we estimated an intercept-only model across the 77 effect sizes (see Table 3) yielded by the seven studies using the R package Robumeta

(Tanner-Smith & Tipton, 2014). The Robumeta package calculated the estimates of heterogeneity ($I^2$- chance variance between-study, and $\tau^2$ – true variance in effect sizes).

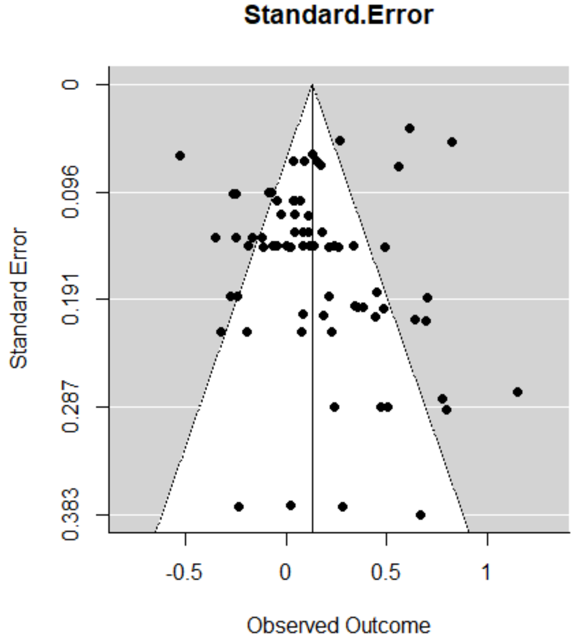
Second, we included moderators in the meta-regression models. While one regression model which includes all moderators is preferable, we did not adopt this approach, because results were not interpretable due to restricted degrees of freedom. Therefore, each moderator was examined in a separate RVE meta-regression model, where each moderator was entered as a predictor. The results are interpreted with caution, because there could be potentially confounding effects of the other moderators. Sensitivity analysis across each model (using $\rho$=0.20 to 0.80) yielded no meaningful differences across models, thereby indicating robust findings across the above stated estimates of $\rho$.

***Publication Bias***

A funnel plot was constructed to visually examine any asymmetry in the distribution of standard errors and effect sizes (see Figure 2). Asymmetry in the funnel plot suggested that publication bias was likely. Secondly, an Egger's test (Egger et al., 1997) was conducted which confirmed our visual findings ($p$=0.033). Therefore, there is statistically significant ($p<0.05$) evidence that publication bias exists in our sample of included studies.

**Figure 2**

*Funnel Plot*




**Results**

In this section, we will first report the results of the main effect. Then we will report the results from the moderator analysis (study characteristics and intervention characteristics). Table 1 provides the results for the main effect and moderator analysis. Table 2 is used to report effect sizes from each study.

***Main Effect***

The overall estimate of 77 effect sizes in the unconditional model (without moderator variables) was 0.149 (SE=0.061, 95%, CI = 0.021 – 0.277) with a *p*-value of 0.025. The value of $I^2$ suggests that 99.06% of the between-study variation was not due to chance, and $\tau^2$ suggests that the true variance in the effect sizes is 0.04 (see Table 1).

***Moderator analysis***

**Study Characteristics.** Among study characteristics, study design, content area, and grade level were not significant moderators of the effect of BL teacher PD at a 0.05 level. However, outcome measure (researcher-designed measures) yielded the effect size 0.145

(SE=0.063, 95%CI = 0.014 - 0.276, *p* = 0.032).

**Intervention Characteristics**. Active use of technology showed a small, significant effect of 0.156 (SE=0.071, 95%CI=0.004-0.308, *p*=0.046). PDs that lasted more than 24 hours (3 days) also contributed a significant effect of 0.157 (SE=0.069, 95%CI=0.013-0.302, *p*=0.035). Fidelity of implementation was a significant moderator when it was *not* measured or specified as low or high, and yielded an effect of 0.125(SE=0.056, 95%CI=0.004-0.245, *p*=0.043). Implementation support offered to teachers did not yield a statistically significant effect size (see Table 4).

**Table 4**

*Main Effect and Moderator Analysis of Blended PD on Student Achievement*

| | | Effect size | SE | 95% CI | *p* | *df* | $I^2$ | $\tau^2$ |
|---|---|---|---|---|---|---|---|---|
| Main Effect | | **0.149** | 0.061 | 0.021- 0.277 | **0.025** | 18.4 | 99.067 | 0.038 |
| Moderator | Code | Coefficient | | | | | | |
| Study design | RCT | 0.238 | 0.131 | 0.128 - -0.098 | 0.128 | 1.99 | 99.030 | 0.040 |
| | QED | 0.106 | 0.064 | 0.121- -0.032 | 0.121 | 1.95 | | |
| Grade Level | Primary | 0.016 | 0.079 | -0.236-0.267 | 0.857 | 3.0 | 99.13 | 0.05 |
| | Elementary | 0.159 | 0.082 | -0.023-0.340 | 0.081 | 10.58 | | |
| | Secondary | 0.272 | 0.171 | -0.274-0.818 | 0.210 | 2.98 | | |
| Content Area | Math | 0.107 | 0.061 | -0.021-0.236 | 0.096 | 16.08 | 99.003 | 0.040 |
| | Science | 0.339 | 0.149 | -0.062-0.740 | 0.080 | 4.27 | | |
| Outcome Measures | Standardized | 0.195 | 0.270 | -1.486- 1.877 | 0.567 | 1.46 | 99.072 | 0.038 |
| | Researcher designed | **0.145** | 0.062 | 0.040- 0.276 | **0.032** | 17.42 | | |
| How technology was used | Active | **0.156** | 0.071 | 0.004-0.308 | **0.046** | 13.50 | 99.093 | 0.043 |
| | Constructive | 0.136 | 0.136 | -0.239-0.510 | 0.371 | 4.0 | | |
| PD duration | More than 24 hrs | **0.157** | 0.069 | 0.013-0.302 | **0.035** | 16.0 | 99.107 | 0.044 |
| | Less than 24 hrs | 0.099 | 0.054 | -0.583-0.780 | 0.317 | 1.0 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Implementation support offered | Yes | 0.096 | 0.061 | -0.036-0.227 | 0.140 | 13.76 3.71 | 99.092 | 0.039 |
| | No | 0.325 | 0.166 | -0.141-0.792 | 0.122 | | | |
| Fidelity of implementation | Reported as high | 0.097 | 0.153 | -0.908-1.260 | 0.556 | 3.77 | 98.850 | 0.031 |
| | Reported as low | 0.612 | 0.000 | | | | | |
| | Not reported/specified | 0.125 | 0.056 | 0.004-0.245 | **0.043** | 13.12 | | |

*Note*. *SE* = standard error; CI = confidence interval; *p* = significance; df = degrees of freedom, Q = test for homogeneity of effect sizes; $I^2$ = measures of effect size variability; $\tau^2$ = between study variance; *n* = 7; *k* = 20; ρ= .80. In the current RVE model, ρ = 0.80 is used as an estimate of between-study variance. For *df*<4, results should not be trusted. Statistically significant (*p*<.05) values are bolded.

## Discussion

The aim of the current study was to explore the relationship between BL in teacher PD and the impact on mathematics and science student achievement. Results show that BL teacher PD does have a small significant effect on mathematics and science student achievement (ES = .149, p=.025). An effect size, in essence, determines the to which our findings are different from the null hypothesis. Our finding supports previous research that PD can help improve student outcomes, but only to a small extent (Hamilton et al., 2003; Fore et al., 2015). Another explanation for this small effect could be that while PD programs might have produced significant teacher learning, the same learning did not translate into teaching practices and instructional changes (Fore et al., 2015). According to scholars, effect sizes must be interpreted with caution because the relevance of the findings are more important than the number (Kraft, 2020; Bakker et al., 2019). However, the variation of effects in the study are considerable, which confirmed the requirement for moderator analysis.

We measured the impact of study characteristics and found researcher designed measures yielded a small but positive effect on student achievement. Among intervention characteristics, active use of technology in PD, longer PDs (3 days or more) and FOI not being reported showed positive effects on student achievement.

It was surprising that no moderating effect of "constructive" use of technology in teacher PD was seen on student achievement. It may be that teachers are reluctant to adopt new pedagogical skills (Kennedy, 2016). PD can be effective if the teachers willingly incorporate the changes in their teaching practices (Buczynski & Hansen, 2010; Kraft et al., 2018), and research has shown that teachers who volunteer to participate in PD engage and practice what they learn differently than those who do not (Bobrowsky et al., 2001). More research is required to understand what leads teachers to benefit from surface level training (active technology use), as opposed to constructing new knowledge (constructive technology use). Additionally, there were no instances in research where an “interactive” technology was used in teacher PD.

Another interesting finding was the moderating effect of FOI not being reported or specified. It is expected that higher FOI would have a larger impact on the effect of an intervention, but in the case of the current meta-analysis the evidence did not suggest so. This puzzling fact can be attributed to the inconsistent and varied use of fidelity components in research (O’Donnell, 2008; Schaap, 2018), and that very few evidence-based frameworks exist for measuring and reporting FOI (Kaiser & Hemmeter, 2013; Stains & Vickrey, 2017). While many researchers are working towards building and disseminating such frameworks (Munter et al., 2018; Tong et al., 2019), a consensus framework for FOI is still to be established. Researchers have also found that compromised FOI can have positive impact on student learning (McKeown et al., 2019a). In other words, even when teachers do not maintain high FOI, there may be low but significant effects on student achievement. Additionally, FOI and need for adaptation and modification can sometimes contrary (McKeown et al., 2019b). Therefore, the PD programs where teachers modified their instructions according to their needs might have had a larger effect on student achievement.

The duration for PDs has been a subject for research, with different researchers advocating different time frames for duration (Didion et al., 2020; Egert et al., 2020). Our findings suggest that a longer duration for the BL teacher PD is more effective than the shorter ones (less than 3 days). Teachers need time to learn new materials (Didion et al,. 2020), and therefore longer duration of PD programs might be more effective.

## Conclusion

We explored certain aspects of the included studies as moderators, but studies can differ on many aspects. There was substantial heterogeneity in the included studies which could not be explained by methodological resolution. Additionally, there was a clear publication bias which could have affected our findings, as studies with non-significant effects may not have been published. Moreover, the existence of confounding variables cannot be ruled out. Also, none of the included studies were found in the What Works Clearinghouse (WWC) repository, and could not have been positively evaluated by the rigorous standards set by WWC.

In the future, PD developers and researchers need to design PD with interactive technology tools for the teachers so teachers can engage in practice during PD and use the technology in ways that are relevant to their curriculum and student body with experts to facilitate and guide that practice (Ball & Cohen, 1999). The current study therefore, brings into focus the urgent need to develop a full picture of how BL teacher PD can benefit student achievement. Urgent research in the field of teacher learning, what variables are important to attain transformational learning, is required. Quality of teacher experiences rather than quantity might have more impact on BL teacher PD.

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# ROLE OF TEACHER PROFESSIONAL DEVELOPMENT IN CLASSROOM TECHNOLOGY USE: A MULTILEVEL ANALYSIS

Information and Communication Technology (ICT) has come to be regarded as an integral part of the current educational systems worldwide, and we are witnessing a surge in educational environments that are embracing ICT driven educational practices. The underlying belief that drives this movement is that ICT use in the classroom improves student learning outcomes. However, studies have presented complex reasons behind increased classroom ICT use. Therefore, researchers and scholars have made attempts to identify and examine the factors influencing ICT use. Some researchers have found that teacher ICT use has more often been influenced by teacher attitudes and characteristics, such as teachers' attitudes, collaboration, gender, years of experience, ICT teacher training, and school characteristics and ICT infrastructure (Aldunate & Nussbaum, 2013; Gil -Flores, Rodríguez-Santero, & Torres-Gordillo, 2017; Petko et al., 2018; Teo, 2014). However, the complexity of the factors influencing ICT use continue to puzzle researchers in the field.

There is a substantial amount of research in the field of ICT and teacher characteristics, and there have been numerous studies examining impact of teacher education on ICT use. Gil-Flores, Rodríguez-Santero, and Torres-Gordillo (2017) found general correlational links between ICT use and teacher professional development (PD). Similarly, Suárez-Rodríguez et al. (2018) found that teachers do not integrate ICT at the pedagogical level, but only at a surface-level. However, their study does not analyze the specific linkage between ICT in teacher professional development (PD) and the subsequent ICT use by those teachers in their classrooms. The purpose of the current study is to examine ICT use in PD and teacher characteristics as predictors to ICT use in teachers' instructional practices.

## Brief Review of Literature

### *School Factors*

Much of the current research in teacher ICT use postulates that school context variables that might be significant predictors of ICT use. Availability of ICT hardware and software is one such predictor; some studies have found that availability of ICT does not always translate into effective use of ICT (Gil-Flores et al., 2017; Petko et al., 2018). Various studies have assessed the importance of  high student-computer ratios, lack of computer availability, and lack of technical and pedagogical support, and found that these elements tend to hinder computer usage in schools (Gerick, Eickelmann, & Bos, 2017). However, in a more recent study, Gerick (2018) found that school context does not make a difference on ICT use after all. School leadership has been found to have a positive relationship with ICT use when ICT is supported directly and a learning climate is fostered by the school leaders (Vermeulen et al., 2017; Wood et al., 2020). Other school context factors, such as educational policies and personnel to train teachers in effective use of ICT have been found to have a larger influence on ICT use (Moreira, Rivero, & Alonso, 2018). Additionally, there is evidence to suggest that while technology use in schools is far from optimal, the research base on improving ICT use in schools is also lacking (Pérez-Sanagustín et al., 2017; Wood et al., 2020 ). Put together, these studies seem to indicate that, while there may be a relationship between school context factors and ICT use, the specific direction and the correlations remain difficult to prove.

### *Teacher Characteristics*

The consensus among researchers on teacher characteristics that determine ICT use remains elusive. While some research has shown that male teachers' classroom ICT use is higher than female teachers. (Scherer, Siddiq, & Teo, 2015), other researchers have found have drawn the same conclusions about female teachers higher use of ICT was compared with male teachers (Wiseman et al., 2018). Even more contradictory findings are reported by studies that have not found any correlation between demographic traits such as, age, gender, teaching experience with ICT use in the classroom (Gil-Flores et al., 2017). Internal characteristics of teachers, like attitudes and beliefs, seem to have a greater impact on ICT implementation in the classroom. Researchers have found that teacher self-efficacy (Barton & Dexter, 2020; Gerick et al., 2017; Petko et al., 2018) and attitudes (Adov et al, 2020; Drossel et al., 2017) are important determinants of ICT use in a classroom. It has also been found that ICT use and teacher instructional practices have a complicated relationship. ICT use in classrooms is influenced by instructional practices, and instructional practices are influenced by ICT use (Suárez-Rodríguez, Almerich, Orellana, & Díaz-García, 2018). The evidence reviewed here for teacher characteristics and their role in ICT seems to suggest a need for further research to understand the complicated relationship among teacher characteristics and ICT use.

### *Student Characteristics*

Student characteristics have also been a subject of research in recent years. For example, there is some evidence to suggest that student ICT use increases as a student's ICT self-efficacy improves (Hatlevik et al., 2018). Some other factors affect student use of ICT are student access to ICT at home, ICT applications at school during lessons, recreational use of ICT, ICT self-efficacy, and interest and enjoyment in ICT (Areepattamannil & Khine, 2017). Other studies identify gender, learning styles, analytic IQ, socioeconomic status and parental attitudes towards technology as important variables in ICT use (Aesaert & Van Braak, 2015; Aesaert et al., 2015). Student characteristics therefore comprise of numerous variables, and the relationship between each of these and ICT use is yet to be fully understood.

### *ICT Use and Student Achievement*

There is a large and growing body of literature investigating the relationship between ICT use in classrooms and student achievement. Some studies have found a positive correlation between ICT use and student achievement (Ferraro, 2018), while other researchers note that positive relationships between ICT use and achievement occur only when ICT is used in an effective manner by teachers (Blanchard, LePrevost, Tolin, & Gutierrez, 2016; Comi, Argentin, Gui, Origo, & Pagani, 2017). Yet other researchers have found no significant difference in student attitudes and achievement (Fabian, Topping, & Barron, 2018). The available literature therefore does not provide us with any consistent evidence of the effects of technology on student achievement.

### *Teacher Education and ICT Use*

A recurring theme emerges from these studies and directs us towards teacher attitudes in the use of ICT. Research has produced some evidence that points to internal attributes of teachers being a stronger influence in the use of ICT than external variables (Drossel et al., 2017; Gerick et al., 2017; Lawrence & Tar, 2018). Therefore, there is a concerted effort among researchers to focus on teacher education programs. Numerous research studies have been undertaken with a focus on pre-service teachers in an attempt to compile evidence on the factors which are directly correlated to ICT integration. Among them, Valtonen, Kukkonen, Kontkanen, Mäkitalo-Siegl, and Sointu (2018) found that pre-service teachers are unable to combine pedagogy and technology effectively. Other studies have found evidence to suggest that fostering positive beliefs about technology among pre-service teachers can assist them in effective ICT use (Parkman, Litz, & Gromik, 2018; Scherer et al., 2015; Scherer, Tondeur, Siddiq, & Baran, 2018).

In a similar vein, contemporary research has also attempted to accumulate evidence for effective ICT training for in-service teachers in the form of professional development (PD). The evidence from some studies point towards constructivist PD programs as having a larger impact of teachers’ ICT use (Alt, 2018). Others have found that simple participation in ICT PD can improve teachers self-efficacy and increase their use of classroom technology (Drossel & Eickelmann, 2017). Koh, Chai, and Lim (2017) found that ICT PD not only assisted teacher in developing ICT rich practices, but also improved student outcomes. Therefore, researchers have called for professional development to develop fundamental ICT skills and making the PD personally relevant (Hubbard, 2018). Together, these studies indicate that there is a pressing need to interpret the intricacies of PD programs and find clearly defined relationships between PD and ICT use.

## Theoretical Framework

The theoretical framework for the current paper is derived from the framework for effective PDs developed by Desimone (2009). Desimone's (2009) has come to be called the consensus model. According to this framework, there are five key components to an effective PD, content focus, coherence, duration, collective participation, active learning. An effective PD provides teachers with content knowledge, structured collaborative experiences involving active learning applications, while keeping in mind state/ district/ school requirements. The goal of such PD is to ensure teachers have the necessary tools for supporting student learning. The five components are defined in Table 1.

**Table 1.** *Definitions and Examples of Key Components of Effective PD (Desimone, 2009).*

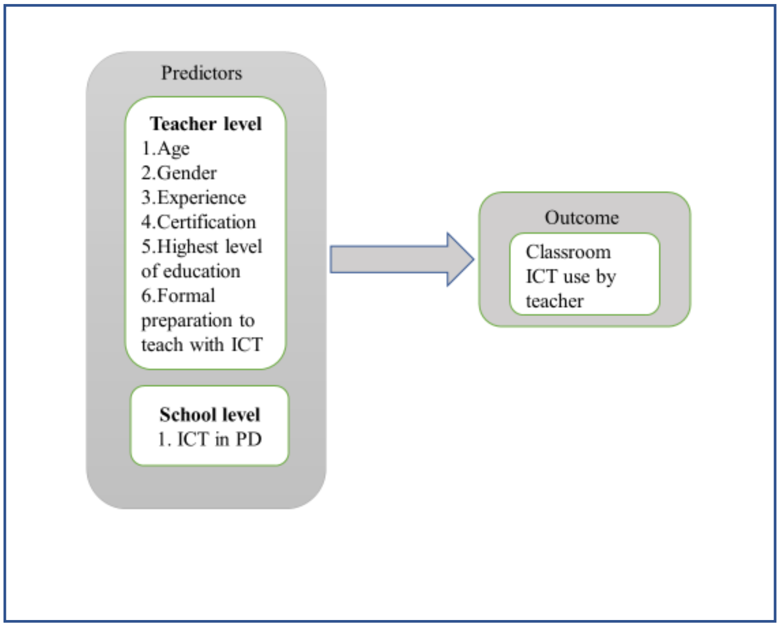
| Terms | Definitions |
|---|---|
| Content focus | PD designed for specific content, eg., math content for math teachers, science content for science teachers, and so on |
| Coherence | PD keeps teacher learning in concord with the goals of state, district and/ or school, eg., PD aligned to Common Core standards for schools that follow Common Core, while PD aligned with TEKS for schools that follow Texas Educational Standards. |
| Duration | Time spent in PD |

| | |
|---|---|
| Collective learning | Teachers learn together in a group of peers or colleagues, eg., with the group of teachers from same school or district |

**Conceptual Framework**

For our conceptual framework we adapted the framework of Guskey (2002), in which he suggested that the first change that occurs in teachers as a result of PD is a change in teaching practices. We chose to adapt the framework because our study analyzes the change in teaching practices based on predictors that are emphasize teacher preparation and educational characteristics. Figure 1 presents the conceptual framework for the current study.

**Figure 1.** Conceptual Framework for Predictors of Classroom ICT Use




### Purpose of the Study

The purpose of the current study is to draw inferences and predictions from the sample of 2560 teachers from grades 7 through 9. We will use 2 level ordinal logistic regression techniques to examine correlational links between ICT in PD programs offered to teachers and the consequent impact of these PD programs on ICT use in classrooms for instructional purposes. We will also examine teacher education and preparation to teach with ICT and the impact of these factors on classroom use of ICT. In doing so, we expect to provide evidence to support the hypothesis that in-service and pre-service teacher education in ICT aids teachers in classroom ICT use.

### Research Questions

1) What is the correlation between classroom ICT use, ICT in PD, and teacher characteristics (age, gender, experience, certification, formal preparation to teach with ICT, highest level of education, preparedness to teach using ICT)?
2) At the school level, how does ICT in PD predict classroom ICT use?

3) At the teacher level, how do teacher characteristics (age, gender, experience, certification, formal preparation to teach with ICT, highest level of education, preparedness to teach using ICT) predict classroom ICT use?

## Method

The current study utilizes the data set obtained from TALIS 2018 teacher survey (OECD, 2018). The surveys are obtained from representative samples of teachers in the US. The TALIS questionnaire provides policy makers and researchers with factors that might be indicative of reforms and improvement in teaching and learning (OECD, 2018).

### *Participants and Setting*

The participants were teachers from US schools teaching in grades 7 through 9. In terms of International Classification of Education these are ISCED-2 level. This selection of grades is frequently referred to as lower secondary level.  There were 2,560 teachers in this sample, from 165 different schools.

### *Variables*

The dependent variable for the current study is ICT use in classroom. ICT use is self-reported by teachers and is categorized into four distinct groups "never or nearly never," "occasionally," "frequently," or "in all or nearly all lessons". In a previous study, Gil-Flores, Rodríguez-Santero, & Torres-Gordillo (2017), used the same dependent variable but collapsed them into two categories, making the results more interpretable. For the purpose of the current study, we will use also use two categories – "users" and "non-users".

We have used one independent categorical school-level variable for RQ2 in this study, categorized under two levels. The first independent variable is ICT in PD. The two categories of response for ICT PD were "yes" or "no".

The dependent variable for the current study is ICT use in classroom. The dependent variable for the study was measured on a yes or no categorical scale, with responses to the question on how often students use ICT for project and classwork were divided into three distinct categories (1 – never, 2- sometimes, 3 - always).

The current study also uses six teacher level independent variables. These are teacher characteristics –age, gender, experience, teaching qualification, highest level of formal education, formal preparation in ICT teaching and preparedness to teach with ICT. The descriptive statistics for teacher characteristics are displayed in Table 2.

**Table 2.** *Means, Standard Deviations and Percentages for Independent and Dependent Variables*

| Variable | Variable type | Percentages | *M(SD)* | Percentage missing |
|---|---|---|---|---|
| Experience | Continuous | ---------- | 13.99(9.41) | 1.4% |
| Gender | 1 - female<br>2 - male | 67%<br>33% | 1.33(0.47) | 0.2% |
| Age | Continuous | ---------- | ---------- | 100% |
| Teaching certification | 1-regular concurrent track<br>2- regular consecutive track<br>3-Alternative<br>4 -Another pedagogical profession<br>5-subject specific only<br>6-no certification<br>7-other | ---------- | ---------- | 100% |
| Highest level of formal education | 3-secondary<br>5-associate degree<br>6-bachelor's degree<br>7-master's degree<br>8-doctoral degree | 0.1%<br>0.2%<br>38%<br>58%<br>2% | 5.63(0.53) | 0.4% |
| Formal preparation in teaching with ICT | 1-yes<br>2-no | 64%<br>36% | 1.64(0.48) | 1.8% |
| Preparedness for teaching with ICT | 1-yes<br>2-no | 81%<br>19% | 1.81(0.39) | 5.1% |
| ICT in PD (*school level independent variable)* | 1 - yes<br>2 – no | 64%<br>36% | 1.36(0.48) | 5.9% |

| | | | | |
|---|---|---|---|---|
| ICT use in classroom *(dependent variable)* | 1-no<br>2-some<br>3-all the time | 3%<br>56%<br>42% | 1.96(0.17) | 5.4% |

## Data Analysis

Since our dependent variable was categorical and ordered, we used ordinal logistic regression techniques as the main procedure for analysis in the current study. Additionally, since schools form clusters we analyzed the data using a two-level ordinal logistic regression. Correlational analysis among the variables was established before the logistic regression was conducted. Variables that were closely correlated were transformed using dimension reduction methods. The two variables, formal preparation to teach with ICT, and preparedness to teach with ICT were found to load into one single factor. However, the correlation between then was not perfect, therefore they could not be computed into a single variable. We decided to discard self-reported preparedness to teach with ICT, and retain formal training to teach with ICT. The reason for this is we believe the latter is a more tangible response, depending on how many courses the participants might have taken in their teacher preparation programs. Missing cases were excluded from the analysis. Age and certification data were missing at 100%, therefore we were forced to discard these two variables from our analysis.

When the dependent or response variable is categorical in nature (in this case classroom use of ICT, yes, some, no), ordinal logistic regression can be used to predict the probability that teachers belong to a particular target group (in this case “yes” classroom ICT use). In the case of the current study, where we are trying to estimate the probability of a teacher using ICT in the classroom given ICT in PD, we could write the probability as Pr(classroom ICT use = yes| ICT in PD)(James et al., 2013) . The values of Pr(classroom ICT use = yes| ICT in PD) will fall between 0 and 1. Therefore, we can predict classroom use of ICT for any value of ICT in PD with the threshold $p<.05$.

In ordinal logistic regression, teachers belong to three different categories for classroom computer use, 1- “never use”, 2- “use sometimes”, and 3- “use all the time”. We want to examine the relationship between ICT in PD and teacher educational variables and classroom ICT use (Norusis, 2020). The general formula for calculating probabilities is

$\Theta_j$= P (score $\leq j$)/P (score $> j$) where probability score of greater than *j* is 1-P(score$\leq j$)

The odds for the three categories for classroom ICT use can be modeled as shown below

$\Theta_1$= P(score of 1)/P(score greater than 1)

$\Theta_2$= P(score of 1 or 2)/P(score greater than 2)

The last category is not included in the calculation of odds because the probability of including the last score of 1.

Therefore, the ordinal logistic model for the current variables is

$\ln(\Theta_j)=\alpha_j-\Sigma\beta_i X_i$ (j = 1, …., J-1; i=1,…M).

Total of J levels where j is one level and i represents predictor variables. In the current study, j=1 is “never use ICT”, j=2 is “sometimes use ICT”, j=3 is “always use ICT”. Similarly, i=1 is “ICT in PD, i=2 is “experience”; i=3 is “formal training in ICT” and so on.

The unconditional model for Level 1 was

$Y^*_{ij}= \beta_{0j}$ where $Y^*=\ln(\text{odds})=\ln[\frac{P(Yij=1)}{1-P(Yij=1)}$

In the case of the current study, Level 1 equation would be

$Y^{*}_{ij} = \beta_{0j} + \beta_{1j}\, age_{ij} + \beta_{2j}\, gender_{ij} + \beta_{3j}\, experience_{ij} + \beta_{4j}\, teacher\_certification_{ij} + \beta_{5j}\, highest\_ degree_{ij} + \beta_{6j}\, formal\_prep_{ij} + \beta_{7j}\, preparedness_{ij} + error$

Similarly, the unconditional model for level 2 was

$\beta_{0j} = \gamma_{00} + U_{0j}$ where $U_{0j} \sim N(0, \sigma^2_{u0})$

In the case of the current study the Level 2 equations would be

$\beta_{0j} = \gamma_{00} + \gamma_{01} ICT\_PD_j + \mu_{0j}$ and $\beta_{1j} = \gamma_{10} + \mu_{1j}$, $\beta_{2j} = \gamma_{20} + \mu_{2j}$, and so on

Combined equation

$Y^{*}_{ij} = \gamma_{00} + \gamma_{01} ICT\_PD_j + \mu_{0j} + \gamma_{10}\, age_{ij} + \gamma_{20}\, gender_{ij} + \gamma_{30}\, experience_{ij} + \gamma_{40}\, teacher\_certification_{ij} + \gamma_{50}\, highest\_ degree_{ij} + \gamma_{60}\, formal\_prep_{ij} + \gamma_{70}\, preparedness_{ij} + \sigma^2_{u0j}$

Logistic regression output produces unstandardized $\beta$ coefficients, which measure unit increase in outcome/ dependent variable with every unit increase in predictor/ independent variable. These coefficients inform us of whether the predictor in question has a positive or negative impact on the outcome, but they are otherwise difficult to interpret. Therefore, odds ratios are calculated using $\beta$ coefficients. An odds ratio is a measure of association between a dependent and independent variable. This measure gives us the probability of the occurrence of an outcome depending on the predictor. In other words, it tells is the probability of a dependent event happening under exposure of an independent event (Crowson, 2020). In the case of the current study, the probability of ICT use in a classroom depending on ICT PD and teacher educational variables (gender, experience, formal preparation to teach with ICT, highest level of education, preparedness to teach using ICT.

## Results

Correlational analysis of the variables is presented below. Classroom ICT use was found to be moderately negatively correlated to ICT in PD, $r(2366) = -.063$, $p < .05$. The variables classroom ICT use and experience were also found to be moderately negatively correlated with r (2418) = -.066, $p<.05$. Classroom ICT use and formal training in ICT use were positively correlated, r(2401) = .074, $p<.05$. Similarly, a moderate positive correlation existed between classroom ICT use and teacher preparedness to teach using ICT, r(2328)=.075, $p<.05$. However, the correlation between gender and classroom use of technology was found to be moderately negative, r (2414) =-.057, $p<.05$. The correlation between classroom ICT use and highest educational qualification was found to be non-significant. The only correlation that was significantly stronger than others was between formal preparation to teach with ICT and preparedness to teach with ICT, r(2410)=.606, $p<.05$. The summary table for correlations is presented in Table 3 below.

**Table 3.** *Summary Table of Correlational Analysis Between Predictors and Outcome Variable.*

| Variables | 1. | 2. | 3 | 4 | 5. | 6. | 7. |
|---|---|---|---|---|---|---|---|
| 1.Classoom ICT use | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| 2.ICT in PD | -.063** | ------- | ------- | ------- | ------- | ------- | ------- |
| 3.Experience | -.066** | -.032 | ------- | ------- | ------- | ------- | ------- |
| 4.Formal training in ICT | .074** | -.110** | -.122** | ------- | ------- | ------- | ------- |
| 5.Preparedness for teaching with ICT | .075** | -.064** | -.125** | .606** | ------- | ------- | ------- |
| 6.Gender | -.057** | .002 | .022 | .046* | .050* | ------- | ------- |
| 7. Highest formal education | .011 | .030 | .240** | .007 | -.016 | -.020 | ------- |

*p<.05. **p<.01

We used the Likehood Ratio Chi-square test to determine model fit. The results from the test informed us that the fitted model is significantly better than the null model (chi-square= 38.037, df=4, $p$<0.001). The target group under analysis was teachers who do *not* use ICT in classrooms.

In the Model 1, the unconditional model, we did not include any predictors, classroom ICT use varies between schools at a significant level ($\chi^2 = 16.57$, $p<0.001$). In other words, a multilevel model that incorporates random intercepts will be a significant improvement over a fixed model which does not incorporate randomly varying intercepts. According to the unconditional model, there is approximately at 14% variance among schools in classroom ICT use. Intraclass Correlation (ICC) was calculated at 0.042 (details of calculation can be viewed in Appendix A), which suggests that there is some evidence of clustering in the data, and this gives us additional justification for the use of multilevel analysis for the current dataset.  Therefore, use of multilevel modeling techniques for this specific analysis is justified.

In the second model, Model 2, ($\chi^2 = 14.57$, $p<0.001$), we included the school level variable, ICT in PD. The results show that ICT included in PD is a significant predictor of classroom ICT use β=-.40, 95%CI[-0.57to-0.22), $p$<.000). These results suggest that including ICT in PD has a negative correlation with classroom ICT use. School level variance decreased marginally in this model to 13.9%.

Model 3 ($\chi^2 = 15.86$, $p<0.001$) examines the random coefficients model where we regressed the teacher level predictors (gender, experience, formal preparation to teach with ICT, highest level of education). The significant predictor in this model was formal preparation in teacher education to teach using ICT (β=.174, 95%CI[0.07to0.30], $p$=.001). From this model we conclude that formal preparation to teach with ICT has a positive effect on classroom ICT use. In this model, the school level variation in classroom ICT use remained at about 14.5%.

In the Model 4, we have included formal preparation to teach with ICT, and ICT in PD in a random coefficients model. Since we had only two significant predictors in the previous model, we examined the random coefficients model for each predictor separately. We found that neither the slope of teacher preparation to teach with ICT ($\beta=.054$, 95%CI[0.01to0.51], $p<.5$), nor ICT in PD ($\beta<.000$, 95%CI[0.00to83238], $p>.5$) varied significantly. Therefore, we have evidence to conclude that these variables are not significant contributors in the school level variation in classroom ICT use. Table 4 presents the summary of the logistic regression results.

**Table 4.** *Ordinal Logistic Regression Results*

| Effects | Model 1 | | | Model 2 | | | Model 3 | | | Model 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | SE | *p* | β | SE | *p* | β | SE | *p* | β | SE | *p* |
| Intercept cut-off 1 | -3.50*** | .122 | .000 | -4.14*** | .1811 | .000 | -4.10 | .282 | .000 | -3.72 | .228 | .000 |
| Intercept cut-off 2 | .37*** | .052 | .000 | -.17 | .132 | .071 | -.11 | .251 | .755 | .273 | .200 | |
| ICT in PD | | | | -.41*** | | .000 | -.40*** | .090 | .000 | -.39*** | .090 | .000 |
| Teaching experience | | | | | | | -.128 | .087 | .127 | | | |
| Formal preparation to teach using ICT | | | | | | | .174*** | .055 | .001 | .254** | .087 | .004 |
| Highest level of education | | | | | | | .017 | .014 | .229 | | | |
| Gender | | | | | | | -.108 | .071 | .127 | | | |
| Wald's $\chi^2$ | 16.57 | | | 15.86 | | | 9.18 | | | 17.10 | | |
| School level variance | 14.4% | | | 14.5% | | | 15.8% | | | 25.2% | | |
| p value chibar$^2$ | .000 | | | .000 | | | .000 | | | .0007 | | |

*p < 0.05, **p < 0.01, ***p < 0.001.

Odds ratios for ICT in PD (OR=.674, 95%CI[.56to.80], *p*<.000) and formal preparation with ICT (OR=1.20, 95%CI[1.08to1.33], *p*=.001) give us a better indication of predictive probability in the case of classroom ICT use. The odds that teachers who received ICT PD use ICT in their classrooms reduces by approximately 67%. The predictive probability that a teacher used ICT in their classroom after getting ICT in PD is 40%. The odds that teachers who received formal preparation to teach with ICT will use ICT in their classrooms is 1.20 times the odds of those who did not. The predictive probability that a teacher will use ICT in their classroom after receiving ICT training in their formal education is about 55%. Calculations for predictive probabilities from odds ratios are presented in Appendix A.

Even though the predictors, ICT PD (*p*<0.001) and teacher preparation to teach using ICT(*p*=0.001) are significant in our model, they do not predict the individual teacher use of ICT in the classroom. Additionally, our model explains approximately 1% (McKelvey & Zavoina, 1975) of the total variance in ICT use by teachers. Calculations of the variance are presented in Appendix A. Our results also indicate that, our model, which included the two significant predictors, does not improve our predictive capacity as compared to the null model.

**Discussion**

In the current paper, we investigated the correlations between classroom ICT use, ICT PD, teacher educational variables (gender, experience, highest level of formal education, formal preparation in ICT teaching). We also analyzed the predictive capacity of ICT PD and teacher characteristics on classroom ICT use, and how classroom ICT use might vary from school to school.

While the results indicate that ICT offered in PD programs is a significant contributor to ICT use in classroom, and that there is some variance among schools in classroom ICT use, there is not enough evidence to suggest that such programs make a sizeable impact on ICT use in the classroom. Some researchers have argued that there may be a disconnect between effective ICT teacher training and effective ICT use (Harris et al., 2009). This disconnect may be due to the general approaches taken toward technology integration in classrooms as many of them are focused on the use of technology as a whole in contrast to the specific learning needs of the students. Harris et al. (2009) go on to suggest that structuring technology PD around specific content areas would yield higher effects. This element of content focus is important in an effective PD (Desimone, 2009). However, other researchers have claimed that such specifications would be difficult to achieve as effective content instruction is very closely related to its pedagogy, and therefore it is may be difficult to separate one from the other in a PD program (Archambault & Barnett, 2010). To complicate matters further, Backfish et al. (2020) suggest that effective use of technology depends on teacher beliefs and not on professional knowledge. A similar finding stressing teacher belief over knowledge in effective technology use has been reported by Saubern et al. (2020). Fore et al. (2015) suggest that the outcomes of PD are subject to complex teacher variables, like teacher perceptions, previous knowledge, and so on. We do not have enough information through the survey questions to determine if the PD was ongoing and teachers received support through the academic school year. Additionally, a recent study by Lui & Phelps (2020) found evidence to suggest teachers tend to lose their learning at around 37 days from PD. If the teachers lost their skills in this time, and received no additional implementation support during their school year, this could account for a loss in technology skills. Put together these studies suggest that PD and ICT use may be linked in many complex ways. Efforts should continue to search for empirical evidence to distinguish and analyze these complex factors. Therefore, we conclude that while PD with ICT emphasis is a necessary condition for ICT use by teachers, it is not a sufficient condition.

With regards to our third research question, we have confirmed that teacher characteristics such as age, sex, and experience did not have a significant effect on ICT use. However, formal preparation to teach with ICT was a significant contributor to ICT use. While these subjects might be a necessary condition for predicting ICT use, they are not sufficient in doing so completely. Some researchers have found that while teacher characteristics do not directly impact ICT use, they may have an indirect effect on it (Inan & Lowther, 2010). Additionally, we have examined teacher educational characteristics and how they predict ICT use, but have not examined teacher beliefs. Researcher have found that internal teacher characteristics, like beliefs, interest, motivation when studies together with external characteristics might be better predictors of ICT use (Ertmer et al., 2012; Ottenbreit-Leftwich et al, 2010; Vongkulluksn et al, 2018). Internal teacher characteristics might therefore need to be studied in relation to external teacher characteristics to understand ICT use in classrooms. Put together, the results of the current study suggest that ICT use in classrooms is not limited by PD programs or teacher characteristics. These areas are clearly ripe for more research and analysis.

## Conclusion

### *Limitations*

As with all self-reported data, there may have been a bias in the selections of answers by the participants. Secondly, while this study analyzes correlations between the predictor and outcome variables, no causal inferences can be drawn from it. Thirdly, some of the missing values could not be compensated for, thereby leading to an incomplete analysis of predictor variables.

### *Implications*

Further research in these areas is warranted as this study has generated little conclusive evidence of the influence of teacher learning on ICT use. Perhaps the design elements of PD programs need to be scrutinized to identify and adjust for the learning and implementation gaps of teachers. While there is a strong research base for the general principals of an effective PD, it might behoove policy makers and developers of PD to get into the fine-grained details of making PD with ICT more effective for specific teacher populations. Since teacher beliefs and attitudes seem to play such an important part in teacher learning, more research needs to be focused on these constructs.

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## STEM TEACHERS' TECHNOLOGY INTEGRATION PRACTICES: THROUGH THE LENS OF COMPLEXITY THEORY

Recent trends in educational technology exhibit two important elements. First, schools all around the world are choosing to embrace computer-mediated learning (Buitrago Flórez et al., 2017; Tondeur et al., 2016), and second, teachers are encouraged to develop digital competencies (Blundell et al., 2020; Straub, 2009). In the recent years, there has been an increasing amount of research on how teachers adopt technologies into their pedagogy and content (Bruggeman et al., 2021; Scherer & Teo, 2019; Lucas, 2020). While several studies have explored the components required for K-12 teachers' successful adoption of technology (Adov et al., 2020; Francom, 2020; Sailer et al., 2021; Atman Uslu & Usluel, 2019), there is little consensus on what propels teacher decisions on technology adoption and integration.

A considerable amount of literature has been published on barriers or challenges to teachers' technology use. While there is a consensus on the types of barriers or challenges, external or first order, and internal or second order (Backfisch et al., 2020; Ertmer, 1999; Ottenbreit et al., 2018), there is still much debate on how these barriers can be overcomed. The current, longitudinal study investigates the differences in teacher perceptions to technology integration barriers as a result of a professional development (PD) program.

Research Experiences for Teachers (RET) in Engineering and Computer Science is a PD program that is designed to enhance the scientific disciplinary knowledge and capacity of STEM teachers and/or community college faculty through participation in authentic summer research experiences with engineering and computer science faculty researchers (NSF, 2021). RETs are designed to equip STEM teachers with authentic tools to bridge the gap between how scientists, engineers, and computer scientists work and how science is taught in schools. The National Science

Foundation (NSF, 2021) has funded several such PD programs in the last three decades, in which universities partner with K-12 schools, and community colleges. In RETs, teachers spend time being immersed in scientific research, while finding ways to apply it to their own curriculum (Blanchard et al., 2009). In recent studies, researchers have investigated characteristics of RETs and characteristics of RET participants (Saka, 2013), teacher perceptions of RET components and teacher satisfaction with RET (Agarwal et al., 2016; Hess, 2017; Thomson, 2019), and the impact of RET (Salzman et al., 2016; Blanchard, 2009). Hughes et al. (2012) extended Blanchard et al.'s (2007) research into changes in teacher conceptions of inquiry, and investigated mentor relationships between teachers and their mentors. However, none of these studies have tried to examine how teacher perceptions of barriers to technology use might change as a result of the RET. The current study uses a complex, mixed methods approach to examine how teachers' perceptions of challenges to technology use change as a result of a technology-rich immersive RET experience.

## Literature Review

### *Brief Review of Literature on Barriers to Technology Use*

Several studies have investigated barriers or challenges to teacher technology use. While there is a consensus on the types of barriers or challenges, external or first order (e.g., school infrastructure, availability of technology, support in implementing technology and so on), and internal or second order (e.g., teacher beliefs and perceptions) (Backfisch et al., 2020; Ertmer, 1999; Ottenbreit et al., 2018), there is much deliberation on how these barriers can be overcome. For example, Francom (2020) conducted a longitudinal survey study (*N*=1,906) to understand change of perceptions to barriers to technology use over time. Evidence from his study suggests that among access, training and technical support, administrative support, teacher beliefs and lack of time were the most significant barriers reported by teachers. In contrast, Adov et al., (2020) concluded that expectancy of required effort, performance, and attitude towards technology were strong predictors of technology use by STEM teachers (*N*=377). Gil-flores et al., (2017) found that availability of technology is not a sufficient condition to influence classroom technology use, but teacher attitude is. The Sanchez-Preito et al. (2019) study had similar findings in which teacher attitudes impact technology use. Taken together, these studies highlight the multitude of variables that can impact technology integration.

Additional barriers include the school context (Tondeur et al., 2017), school leadership and their role in technology integration (Hew & Brush, 2007), technology PD (Ertmer et al., 2012; Shimasaki, 2015) or a vision for technology implementation by school/district level personnel (Balanskat et al., 2013; Levin & Schrum, 2013; Tondeur et al., 2017). In a recent study on how external barriers influence technology use, Lucas (2020) found that several external barriers (e.g., technology infrastructure, content and curriculum, PD, and organization and leadership) negatively impact the technology use in classrooms. Overall, the evidence suggests that while scholars agree on how barriers to technology use impact educational practices, they are not in consensus over how the problem should be resolved.

***Brief Review of Research on RETs***

Research Experience for Teachers (RET) is a PD program which equips teachers with authentic tools to bridge the gap between how scientists work and how science is taught in schools. The National Science Foundation (NSF, 2021) has funded several such PD programs in the last two decades. In RETs, teacher spend time being immersed in scientific research, while finding ways to apply it to their own curriculum (Blanchard et al., 2009). Blanchard et al., (2009) found that participants became more confident with research on microbiology, and their conception of scientific inquiry changed from a method of teaching to a more investigative approach. There was also a slight but observable increase in some of the teachers use of higher-level Bloom’s taxonomy when framing student questions. However, the researchers also concluded that each participant took something different from the RET, depending on their prior knowledge and experience.  Hughes et al., (2012), extended Blanchard et al.,'s (2009) research into changes in teacher conceptions of inquiry, and investigated mentor relationships between teachers and their faculty mentors. Three case studies revealed that each teacher experienced a different type of mentoring, and all three types of mentoring improved teacher understanding of scientific inquiry. Thus far, these studies examine and explain teachers learning of scientific inquiry, but they do not undertake to form an understanding of teacher technology use.

In another study, Saka et al. (2014) investigated characteristics of RETs and characteristics of RET participants and found the pedagogical components of RETs helped relate research experience with classroom experience. Previous research has also revealed that teacher perceptions of RET components and teacher satisfaction with RET were positive (Agarwal et al., 2016), but implementation of their learning required more scaffolding. Salzman et al., (2016), also evaluated the impact of RET on teachers and reported that participants were more confident in research practices, and their ability to engage their students in STEM research. More recently, Thomson and Turner (2019) examined how emotions, motivations and changes in instructional practices were correlated to teachers RET PD experiences. In another RET study, Hess et al., (2017) explored teacher satisfaction with the RET, changes in teacher content knowledge, perception and epistemological beliefs on nanotechnology. They also studied the integration of nanotechnology modules in three teacher classrooms. They found teachers were satisfied with RET, and showed an increased awareness of nanotechnology; their students also showed an increased knowledge of nanotechnology. They did not, however, examine the impact of their specific RET on technology integration in general. They found that the teachers' emotions were an important component of how they changed their teaching practices. Most RET researchers have been primarily focused on the impact of RET on teachers, but not on their technology use. Collectively, these studies outline a critical need to examine how RETs may influence technology use in participating teachers.

The evidence reviewed here suggests there is a paucity of research in how PD can impact the teacher perceptions of barriers to technology use. In the current study, we examine how technology-integrated PD shifts teacher perceptions of barriers to technology use.

**Theoretical Framework**

Due to the complex nature and non-linearity of the constructs of teacher learning, we draw from the assumptions of complexity theory (Davis & Sumara, 2006). A central idea in the theory is that complex systems are more than parts of the whole (Cochran-Smith et al., 2014). There are five important elements in a complex system: (a) nestedness and interactions of systems with each other, (b) interactions are non-linear in nature, (c) systems are not in equilibrium, (d) even small changes might have a large impact and vice versa, and (e) these systems are in an emergent state (Cochran-Smith et al., 2014). Opfer and Pedder (2011) suggest teacher professional learning can be classified as a complex system because of the existence of several subsystems which interact dynamically with each other. They describe the teacher, the school, and the learning activity as three different subsystems.

Teacher education is nested within many frames and contexts, like content and pedagogical knowledge, school policies and curriculum, student demographics, availability of technology resources, and so on. As teacher learning emerges from a multitude of constructs, we need to examine multiple levels and systems synchronously. Also, we need to understand different aspects of these constructs, while keeping in mind the emergence of new dynamic interactions of these aspects (Ovens, 2017). For example, when teachers attend a PD program with the school district, they take that knowledge, and interpret and utilize it as an individual within the context of their classroom and according to their student dynamics. Teachers draw on their own experiences, which are relational to the teachers' knowledge and skills, which in turn are intertwined in complex ways to how teachers structure their individual teaching. Therefore, teacher learning which is modified or augmented can produce completely unpredictable and emergent outcomes, which produce a disequilibrium in the system. Each construct forms a network with one or more constructs, and a dynamic relationship exists among these constructs. Complementary systems like teacher learning and teaching practices therefore benefit from being examined through the complexity theory lens. Examining teacher learning in a non-linear manner might have a significant impact on the transformative potential of teacher PDs.

Scholars have argued in favor of the multidimensional approach to PD (Evan, 2014; Opfer & Pedder, 2011), while others have suggested reducing complexity within teacher learning by narrowing definitions of teaching practices, and measurable change in teaching practices and student learning (Gore, 2021). In the current study, we focus on the complexities of teachers' adoption and utilization of technology. The complexity theory lens is especially suited for this purpose because learning and teaching occur as reciprocal activities, which are nested within the classroom, school, or district.

**The Current Study**

The current study draws from the broad premise that PD can impact teacher learning, and seeks to understand the complex inter-twining of technology elements in the PD and teacher learning. The hypothesis for the study is that this immersive PD and experiential learning leads to transformative changes in teacher knowledge and skills for technology use. Using mixed methods research and drawing from complexity theory, we try to situate changes in teacher learning into connected understandings of their enacted practices aggregated across the three years of the PD.

In the intensive six-week Research Experience for Teachers (RET) Program, teachers were provided with structured research experience in a university laboratory while working with faculty mentors, their graduate students and other related research groups (NSF, 2012). In these settings, participating teachers learned to work on technology-rich research activities and projects. Additionally, the teachers were provided opportunities to participate in community activities, and professional sessions with industry partners from the STEM professions, like technology and manufacturing companies.

## Research Questions

- How do teacher perceptions of external barriers to technology use change as a result of a Research Experience for Teachers (RET) PD?
- What common themes emerge after the completion of RET PD?

## Method

### *Participants and Setting*

The six-week professional development was held on campus in a large public university in Central Texas. The participants were teachers who currently taught in local area middle schools, high schools and community colleges, and were recruited through email. For each year of the study, emails were sent to local area schools and community colleges to seek out interested teachers. The participating teachers were paid approximately $7,500 for their participation in the program. Teachers who taught mathematics, computer science, career and technical education or STEM subjects at the post-secondary level were given preference, but there was no rule to exclude other content areas. Each year, there was space for ten teachers to participate in the project. Each year, two to three teachers from the same school were selected to support collaboration at the campus level. However, since the funding for the project was approved at a late date, there were only 9 teachers recruited the first year, 2017. Similarly, there were 9 teachers recruited during year 3, 2019. Each year two of the participants from the previous year asked to participate in the PD again. Therefore, while there are 28 teachers in the sample, the responses of 24 participants are analyzed in this study. Two to three teachers were assigned to a research group, forming four research groups every year. As a matter of detail, the participants were not recruited by the researchers, but by the leadership team of the RET program. Hence, we used a convenience sample for the current study. Details of teacher demographics are presented in Table 1.

**Table 1.** *Teacher Demographic Information by Year*

| | | 2019 (*N*=5) | 2018 (*N*=9) | 2017 (*N*=9) |
|---|---|---|---|---|
| Subjects taught | Math | 75% | 64% | 44% |
| | Engineering | 25% | 0% | 0% |
| | Computer Sc | 12.5% | 9% | 22% |
| | Robotics | 12.5% | 9% | 0% |
| | Technology | 0% | 18% | 22% |
| | Non-STEM subjects | 0% | 9% | 0% |
| | Other | 12.5% | 36% | 11% |
| Race/ ethnicity | Non-white Hispanic | 87.5% | 73% | 100% |
| | Asian | 12.5% | 18% | 0% |
| | Hispanic/Latino | 12.5% | 9% | 0% |
| | More than one race | 12.5% | 0% | 0% |
| Gender | Male | 25% | 36% | 78% |
| | Female | 75% | 64% | 22% |
| Age | >30 years | 25% | 27% | 11% |
| | 30-39 years | 25% | 27% | 22% |
| | 40-49 years | 25% | 18% | 33% |
| | 50-59 years | 12.5% | 18% | 22% |
| | >60 | 12.5% | 9% | 11% |
| Experience | 1-5 years | 38% | 46% | 33% |
| | 6-10 years | 13% | 27% | 44% |
| | 11-15 years | 13% | 9% | 22% |
| | 16-20 years | 25% | 0% | 0% |
| | >20 years | 13% | 18% | 0% |
| Grade level taught | Junior high/middle | 40% | 36% | 0% |
| | High school | 60% | 54% | 76% |
| | Two-year college | 9% | 9% | 22% |
| Highest educational level | Bachelor’s | 25% | 55% | 33% |
| | Master’s | 38% | 36% | 33% |
| | Graduate work but no advanced degree | 13% | 9% | 22%<br>11% |
| School location | Rural | 50% | 27% | 33% |
| | Urban | 25% | 27% | 44% |
| | Suburban | 25% | 46% | 22% |

| | | | | |
|---|---|---|---|---|
| School type | Public | 63% | 82% | 78% |
| | Charter | 13% | 0% | 0% |
| | Community College | 25% | 0% | 22% |
| | Other | 0% | 0% | 0% |

**Program Description**

The RET was held in a large public university in Central Texas, and was a collaborative effort between faculty and program staff in the Department of Computer Science and Engineering, and the College of Education and Human Development. The Secure Teacher Education by Utilizing Research Experiences (SECURE) program was designed for local secondary teachers and community college faculty to gain new knowledge and insights about engineering research in the area of cybersecurity. Overarching program goals included: increased cybersecurity curriculum offerings, encourage more students to explore cybersecurity careers, and increase exposure to a broad range of cybersecurity applications.

We sought to achieve these goals through two major components (academic and professional).

Academic: Teachers will gain experience in the research and applications of cybersecurity through:

- Engaging in an intensive six-week research project focused in cybersecurity research through seminars, education and curriculum design workshops, research group meetings and engagement with industry partners.
- Gaining new knowledge of professional practice in mathematics and engineering related to cybersecurity, and the social impact of engineering innovation that can be integrated into their curriculum to educate students about STEM-related educational and career activities.
- Teachers also engaged with the teacher educator each week in a curriculum design setting. They were introduced to backwards curriculum design and engaged in

backwards design approaches throughout the program. They identified areas where new curriculum innovation/products could be integrated based on their research experiences.

- Participants developed units, comprised of lessons plans, scientific or engineering design activities, and assessments for implementation in their classrooms.
- A final program deliverable was for teachers and instructors to disseminate [upload] all of their curricular products to the peer-reviewed TeachEngineering.org website.

Professional: The program will increase the capacity, confidence and leadership of teachers to implement a new vision for STEM learning that will impact their classroom and community by:

- Building a professional learning/resource network of engineers/computer scientists, and fellow teachers through working together in a research team, and maintaining communication with program faculty throughout the academic year.
- Disseminating results of their research experience at local, regional, or national conferences.
- Serving as RET Site ambassadors who readily discuss their experience with new teachers.

The RET was designed to immerse the participants in the use of cybersecurity related resources and applications (e.g., computer hardware and software) while working in laboratories of Computer Science faculty and their graduate students for 6 weeks. Through the week, the participants received training in their specific research groups from the Computer Science faculty and graduate students, and worked on a group project in the computer lab. At the end of each week, they met with a teacher educator from the College of Education to go over their research project and explore applications of it in their own classrooms. At the end of the six-week period, each teacher was required to submit their curricular designs (a unit with lessons). They gave a poster presentation summarizing their research team project they conducted in the computer labs. They were also required to submit written reflections on how their research experiences could be connected to their real classrooms, and on the value of their research experience.

In addition to the $7500 stipend for participation in the program, benefits included $1500 to purchase materials for their classrooms, and registration and travel funds to attend the STEM4Innovation Annual Conference.

***Procedures***

Two different researchers conducted the data collection; one researcher collected the survey data, took field observations, and informal conversations, while another collected the teacher reflections and teacher artifacts. All participants were emailed the pre-survey before they attended the first day of the PD. The facilitators of the PD program also assigned a time period of approximately 10-15 minutes for the participants to complete the pre-survey before the commencement of the PD program. A researcher was present at this time to answer questions about the survey, is any arose.

During the last day of the PD program, approximately 15-20 minutes was once again set aside by the facilitators for the participants to complete their post-surveys. Again, a researcher was present on the premises to answer any questions or concerns regarding the survey. This process of administration was repeated itself every year for each cohort.

The participants also wrote and submitted a page long reflection on how they would connect their RET learning with their classroom instruction. The reflections were completed before or immediately after the post survey was administered. In other words, the data for the post survey and the reflection were collected almost concurrently.

### *Survey Instrument*

The survey instrument was adapted from a SRI International survey which was developed to examine NSF supported research experience for undergraduate students (Russell, 2006). The adapted pre-survey contained 48 items, of which 45 were ordinal or categorical, and the rest were open-ended. The post survey contained 50 ordinal or categorical items, and 5 open-ended responses. Both the pre and post surveys were divided into several sections, each measuring a different construct. Detailed information on the individual sections is provided below.

**Teacher and Student Information (Pre-survey Only).** The survey opened with a section on teacher information. This section had 19 questions and asked teachers their names, age, ethnicity, their grade levels, subject areas taught, type of school they taught in, location of the school. Teachers were asked about how long they had taught, their highest level of educational qualification, and the subject in which they received their highest degree. It also asked the participants about the composition of their student body like the percentage of students who were eligible for free and reduced lunches, percentage of students who had internet access at home.

**Impact of RET on Awareness of Aspects of STEM Teaching.** In this section, teachers were asked to estimate the effect of the RET on their awareness of various technological resources and tools, STEM issues, STEM career options, general knowledge base in STEM pre and post the intervention. A 4-point Likert scale was used to answer the 6 questions in this section, 1 being None, and 4 being A lot. Cronbach's alpha was measured at 0.95.

**Impact of RET Program on STEM Attitudes and Beliefs.** There were 5 items in this construct, asking teachers about their ability, confidence, motivation and skill in teaching with technology in their classrooms. Teachers selected from a 5-point Likert scale with 1 being None, and 5 being Have no idea.

**RET Program Influence on Research Practices.** This section had five questions and was dedicated to understanding the teachers' perceptions of the RET experiences, both before and after the intervention had taken place, and how it had changed their perceptions of STEM research practices. It contained questions like RET and understanding research practices, scientific knowledge, applications of STEM, ethical dimensions of STEM and so on.

**RET Program Logistic Experiences.** In this section, the participants were asked how well the basic logistics of the RET coordinating team worked for them. The questions in this section included information on information about the program, contact with the program manager, scheduling, program logistics and so on. There were seven questions in this section.

**Satisfaction with Program (post survey).** In order to understand how to better serve the participants, this section had 20 questions included questions about interactions with mentors, faculty, graduate students, as well as satisfaction with the stipend. It also asked participants how satisfied they were with how they were able to transfer the knowledge gained from the PD program to their classrooms.

**Challenges to Technology Integration.** The participants were asked to identify external challenges that they might find when trying to teach what they had learned. This section therefore included questions like lack of computers and internet, lack of time, lack of admirative support and so on. Teachers were asked to select each obstacle they felt they might face in integrating technology into their classrooms. The choices were therefore dichotomous, in which each individual teacher selected as many obstacles he/she felt were applicable to him/her, while leaving the others unselected.

**Open-ended Questions (pre survey).** This pre survey had three open-ended questions asking the participants to write more about the challenges they thought they might have to face, why they joined the PD program and how they thought it might help their classroom instruction. Questions included in this section were “Why did you choose to participate in this program?”, “How do you think this summer program will help your classroom instruction?”, “What are some challenges you think you might face when trying to implement what you have learned this summer into your classroom?”

**Open-ended Questions (post survey).** There were five open-ended questions in this section, about the best aspects of the program, suggestions for improvements, comparing with other professional development programs, integrating the RET into the classroom, and possible difficulties in integration. Questions in this section were “What do you think were the best aspects of your RET experience this summer?”, “How could this PD be improved?”, “How would you compare this PD with others that you have attended?”, “What are some difficulties you anticipate in implementing what you have learned in the RET experience?”

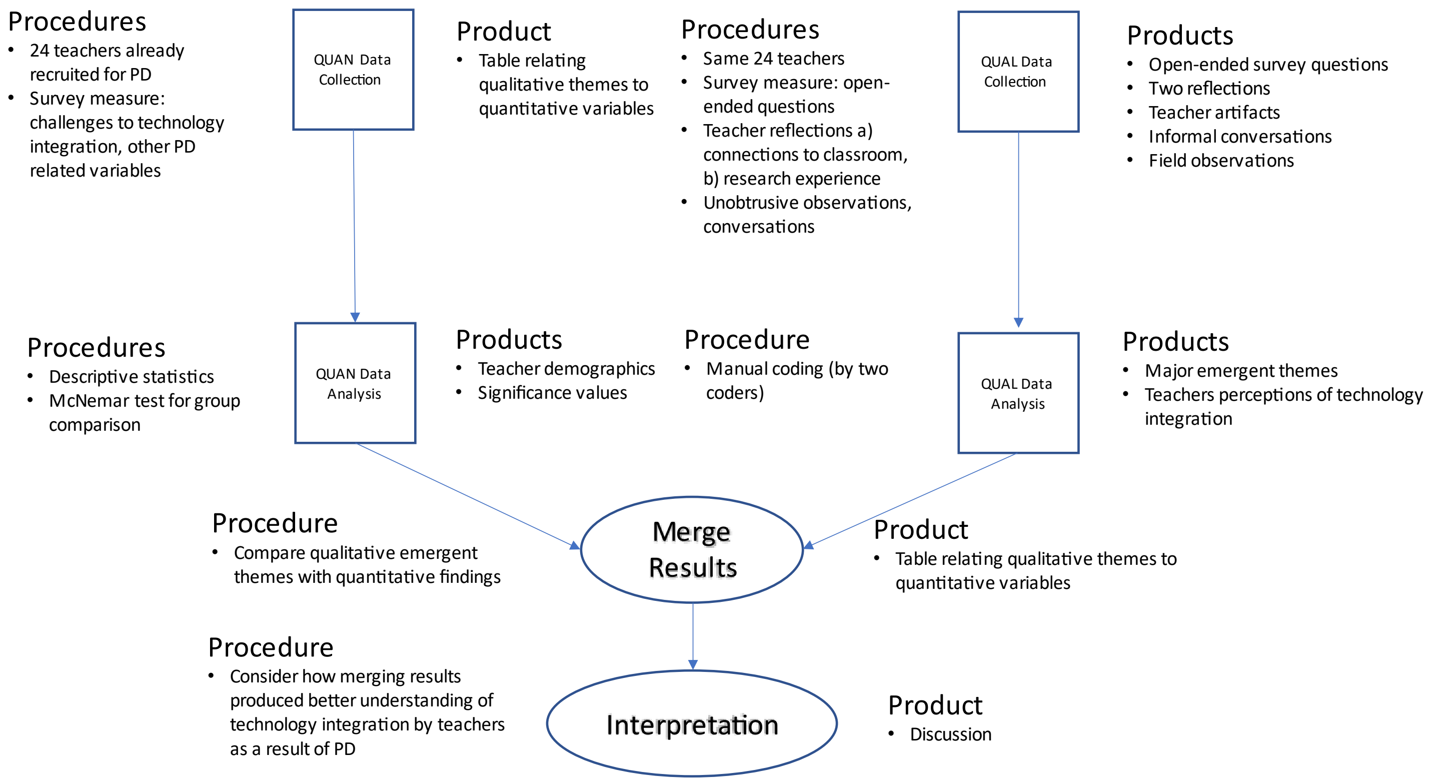
### Data Analysis

For the purposes of the current study, I have employed a mixed methods approach to data collection and analysis. Mixed methods is defined by Johnson et al., (2007) as “….. the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration.” (p 123).

A mixed methods technique is suitable for the current study because through mixing of qualitative and quantitative data triangulation can be achieved. Triangulation is an important element in mixed methods as it can confirm or corroborate one source of data with another. Another reason is combining two types of data analyses can help the researcher develop richer and more meaningful conclusions (Lopez & Teddlie, 2009; Rossman & Wilson, 1985). Therefore, mixed methods may provide a richer and deeper understanding of the answers to the research questions.

The type of design used for the current study has been termed convergent (or concurrent) design by Creswell and Clark (2018). In this design, qualitative and quantitative data are collected and analyzed simultaneously. The main purpose of this research design is to triangulate qualitative results with the aid of quantitative data analysis. The qualitative data provided the participants perceptions of the interaction of these key variables, and the quantitative data in the current study provided the researchers with the important variables for the analysis. A complete picture of data collection and analysis is presented in Figure 1.

**Figure 1.** *Procedural Diagram for Convergent Mixed-methods Design (adapted from Creswell and Clark, 2017)*



### ***Quantitative Data Analysis***

To determine if there was a difference between the pre-survey responses and post-survey responses to obstacles to technology use, we used a non-parametric technique to evaluate the paired responses, the McNemar test (1947). This technique is used to calculate within-subject mean differences measured on a binary or nominal scale (Adedokun & Burgess, 2012; Boduszek, 2016). The assumptions for the McNemar test are (a) data comes from paired subjects, (b) the variables are measured on a binary or nominal scale, and (c) subjects are independent from each other (https://www.statisticshowto.com/mcnemar-test/, 2021 March). In very simple terms, the McNemar test is a 2X2 table which compares proportions of responses from paired samples. A typical 2X2 table is presented in Table 2.

**Table 2**

*2X2 Contingency Table for Pre and Post Scores*

| | Pre | Post |
|---|---|---|
| Pre | A | B |
| Post | C | D |

$$\chi^2 = \frac{(A-D)2}{(A+D)}$$

where A and D are the concordant rows and B and C are the discordant rows. Discordant responses are those that are different between pre and post, while concordant responses are the ones that are not different between pre and post. To simplify, for significant difference between pre and post responses, we need a larger proportion of discordant responses in our data. However, the results indicate that there is no significant difference between pre survey responses and post survey responses to questions on obstacles to technology use. The results from the McNemar test are reported in Table 3.

**Table 3**

*Results of McNemar Matched Pair Test for Obstacles to Technology Use*

| Variable | Discordant pairs | Concordant pairs | McNemar's $\chi^2(1)$ | *p* | Odds Ratio | 95% CI |
|---|---|---|---|---|---|---|
| 1 | 7 | 17 | 3.57 | .125 | .167 | .004-1.374 |
| 2 | 5 | 19 | .20 | 1.00 | .667 | .056-5.820 |
| 3 | 2 | 22 | 2.00 | .500 | -------- | -------------- |
| 4 | 9 | 15 | 2.78 | .180 | 3.5 | .666-34.530 |
| 5 | 9 | 15 | 1.00 | .508 | 2.0 | .427-12.359 |
| 6 | 8 | 16 | .50 | .727 | .6 | .093-3.084 |
| 7 | 3 | 21 | .33 | 1.00 | .5 | .008-9.605 |

*Note*: 1 - Not enough time on your part to prepare new lesson/lab plans, etc , 2- The scientific/math topics are too different , 3- Materials, equipment, etc. are too expensive, 4- Other teachers or administrators at your school are resistant to your proposed changes, 5- Your school's curriculum is inflexible, 6- Your school has poor/no access to computers/Internet , 7- Materials, equipment, etc. that you are planning to use are not yet available.

Teachers indicated in their pre-surveys that the two biggest barriers were lack of time, and difficulty of the topic in question. A common occurrence post RET was that more teachers felt the topics were too hard than in the pre-survey. In 2017 and 2019, post survey responses indicated that more teachers thought they would face a lack of time than they did in their pre-survey. See Table 3 for percentage change in pre and post survey responses.

**Table 3**

*Obstacles by Year*

| Nature of challenges | 2019 pre | 2019 post | 2018 pre | 2018 post | 2017 pre | 2017 post |
|---|---|---|---|---|---|---|
| Not enough time on your part to prepare new lesson/lab plans, etc. | 50.0% | 54.7% | 36% | 36% | 11% | 33% |
| The scientific/math topics are too different | 37.5% | 66.7% | 73% | 82% | 77% | 88% |
| Materials, equipment, etc. are too expensive | 37.5% | 11.1% | 46% | 36% | 44% | 11% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Other teachers or administrators at your school are resistant to your proposed changes | 25.0% | 22.2% | 18% | 18% | 0% | 11% |
| Your school's curriculum is inflexible | 12.5% | 33.3% | 27% | 27% | 0% | 0% |
| Your school has poor/no access to computers/Internet | 12.5% | 0% | 9% | 0% | 0% | 0% |
| Materials, equipment, etc. that you are planning to use are not yet available | 12.5% | 0% | 27% | 1% | 33% | 22% |

***Results***

While the McNemar test did not yield any significant differences between pre and post survey responses, the descriptive statistics does show us some shifts in teacher perceptions through the percentage responses. The qualitative analysis yielded some interesting themes, and is discussed in the next section.

***Qualitative Data Analysis***

We used five different sources of qualitative data to triangulate our findings; open-ended survey questions, teacher reflections (two reflections from each teacher, one on how to connect their research to their classroom teaching, and the other on what their research experience had been like, 48 in all), teacher artifacts, hand-written field observations, and informal conversations. Teacher reflections were coded by two coders; the first coder (first author) was a researcher who had been a part of the research team for the RET, and coder two was an undergraduate student with no connection to the RET. First, coder one coded six documents (from three different teachers) and identified four common codes in those reflections. Second, coder one trained coder two by reviewing six additional reflections (from three different teachers) together where they detected the previously identified commonly occurring codes, and identified one more new code. Third, they agreed to explore the rest of the reflections using these common codes, and to continue coding the rest of the reflections using inductive processes. Fourth, coder one and coder two then coded six more reflections (from three teachers) separately. Fifth, they came together to ascertain inter-rater reliability (IRR). IRR was established at 85%. Finally, the first coder read and coded the remaining reflections deductively using the previously generated coded.

The open-ended survey questions were also coded using the same technique, and IRR for them was established at 95%. The reason for this difference in IRR was that the open-ended survey responses were much shorter, and frequently yielded only one single code. The first author then proceeded to examine the informal notes on the field observations and conversations with the participants to gain a deeper understanding of the themes which emerged from coding the reflections. Finally, teacher artifacts (lesson plans and poster presentations) were examined by the first author to verify the themes emerging from the previous data. We did not examine the qualitative data with any a priori themes in mind, but let the themes emerge as we coded each document/artifact. The complexity of the data and the analysis made it essential to code each source inductively. An overview of the data sources, collection, and analyses are presented in Table 4.

**Table 4**. *Data Sources, Collection and Analysis for Qualitative Data*

| Data source | Collection | Purpose of data source |
|---|---|---|
| Reflection – connection to teaching | Post PD | Extract and compare emerging themes (Hays & Mckibben, 2021; Lincoln & Guba, 1986). |
| Reflection – research experience | Post PD | Extract and compare emerging themes (Hays & Mckibben, 2021; Lincoln & Guba, 1986). |
| Open-ended survey questions | Pre and post PD | Extract and compare emerging themes (Hays & Mckibben, 2021; Lincoln & Guba, 1986). |
| Field observations | During PD | Thick description (Lincoln & Guba, 1986). |
| Informal conversations | During PD | Thick description (Lincoln & Guba, 1986). |

| | | |
|---|---|---|
| Teacher artifacts | Post PD | Interpret and synthesize (Hays & Mckibben, 2021; Lincoln & Guba, 1986). |

There are five sources of data involved in explaining pre and post differences, and other emerging themes of the teachers attitudes and perceptions towards the RET PD. We report the results from the different data sources in in different tables, in an attempt to simplify complex relations among them. We have, however, divided our findings into two parts to identify shifts in teacher attitudes and perceptions, pre-program data and post program data. In Table 5, we have assembled the open-ended responses to the questions in the pre and post survey. In table 6, we have recorded the responses for the emergent themes from teacher reflections, and combined them with the responses from the pre and post open-ended surveys.

**Table 5.** *Teacher Perceptions of Challenges to Technology Use*

| Theme | Quotes (pre-survey) | Quotes (pre-survey) |
|---|---|---|
| Topic too complex | "the specific topic I was selected for may be too complex for both me and my students"<br>"The level of the courses has to be appropriate for more advanced topics to be included"<br>"I'm concerned that it might not seem relevant to students"<br>"Much of my instruction is more Algebra related than programming" | "My subject is a foundational skill for the research - very difficult to bring the research down to Algebra level."<br>"Being able to take a complex programming topic and converting it into a HS Project based physics course."<br>"Comparing the level of the project I was assigned to the level of the class I teach there is a vast difference in both topics."<br>"My students aren't programmers, coders, or computer scientists. They'll be able to do only so much with cybersecurity/steganographic principles."<br>"This is going to make it very hard to try and bring in the idea of Quantum Cryptography."<br>"The actual research did not fit in to my subject areas as it was way above their knowledge level and had no state standard that matched up to it"<br>"The specific research is not applicable to my classroom"<br>"That the math is very high level and a lot of it will be lost in translation to my students." |

| | | |
|---|---|---|
| | | “The research with the grad student has very little application to what I am teaching or will be teaching” |
| Time | “Time is my main concern. I only have three hours and forty minutes a week to teach and explain a huge amount of material”<br>“One of the biggest challenges I might face is time”<br>“I imagine that the typical issues will arise, too much information and too little time to deliver the content.”<br>“I am afraid that my lessons may not be timed correctly or appropriate for my group of students” | “Finding the right time to implement it”<br>“Just finishing all the preparation of lessons and activities.”<br>“I don't have the time in my teaching schedule/scope and sequence to implement lengthy projects and lessons” |
| Access to materials | “students ability to access the required materials. Many are low-income.”<br>“finding the equipment to use for my classroom” | “Cost of materials” |
| Administrative support | “Following district/state required lesson objectives and including RET learned topics” | “I expect to have difficulty getting these topics into my syllabus.”<br>“Another issue is that since there are 20+ other instructors teaching the same topic I can't in good conscience make this material required. It will probably be spread out as bonus assignments or something like that.” |
| Lack of confidence with technology use | “I'm not real good with computers, and the discussion of coding makes me a little nervous.” | |
| Student interest/buy-in | | “I also worry about student interest”<br>“I won't have buy in from my students since cyber security and Geometry aren't connected”<br>“Student push back” |

**Table 6**. *Emergent Themes and Supporting Quotes*

| Themes | Quotes (pre-survey) | Quotes (post-survey) | Quotes (post-program reflections) |
|---|---|---|---|
| Professional learning | "To learn about a new field in computer science"<br>"To learn more about the opportunities of cyber security as a new career for my students"<br>"To learn and grow personally"<br>"To improve my knowledge of current trends in Computer Science"<br>"A great learning opportunity"<br>"Great opportunity both educationally and financially"<br>"I was encouraged to participate by my colleagues"<br>"I was encouraged to apply by district leadership"<br>"To better myself as a teacher and have more knowledge to share with students"<br>"Our school is interested in offering a cybersecurity option"<br>"Recommended by another instructor who had attended last year"<br>"Encouraged by school administration"<br>"To gain more insight into different areas of computer science and engineering"<br>"An additional tool for me"<br>"I need to find more ways to engage my students" | "Collaborating with my teacher colleagues/participants in RET"<br>"The lectures, discussions and advisories" were good<br>"Relating material to the classroom was difficult<br>"Getting to explore research topics that can be related to math curriculum"<br>"Lectures from the variety of speakers" was great<br>"I'd like to get a little more of the individual topics rather than just focusing on one major one"<br>"This is the longest workshop I've attended, but it was very rewarding. I learned a lot and developed great communal relationships."<br>"Keep information at a level the teacher can digest. Some concepts were way too hard." | "Visiting the lab where the physical work was being done on the vehicles was tremendously helpful. It helped me develop a vision for my unit and student learning"<br>"I will share pictures and information about the project at the University and other examples"<br>"I had to understand a way to connect this to one of my classes, Animation, Game Design, or Yearbook"<br>"Through interaction with a graduate student at the University, I was shown the most common types of attacks that hackers will use to steal information from the internet" |

| | | | |
|---|---|---|---|
| Personal interest | "I have always been interested in research and this was a chance to experience it at a highly respected institution"<br>"I have a general interest in computing"<br>"Learning something new is refreshing in itself"<br>"I love STEM and all it has to offer"<br>"I like to be more informed about cyber security"<br>"Being a student again helps me relate to my students" | "I enjoyed listening to needs and current lack of Cybersecurity"<br>"I enjoyed getting to meet and interact with teachers from different schools in the area"<br>"I love the hands-on experience of working with our project" | "Securing the Mars rovers from security breaches may not be an immediate threat but NASA itself has been the target of data breaches. I see it as something that is inevitable, whether deliberate or accidental"<br>"Throughout this research process I learned about Quantum Computers and how they work"<br>"I enjoyed learning about the vast world of cybersecurity from an array of professionals" |
| Gaining confidence | Become "more confidence in applying STEM and technology in the everyday classroom"<br>"give me the necessary understanding of a principle that I am not that familiar with"<br>"It is the content I am more interested in that will help me teach" | "I would have liked more guidance from my PI translating the material into my curriculum"<br>They need to "make it more relevant to our content areas"<br>"Help bring research concepts to our level better"<br>"I will go back to my classroom with a greater knowledge and passion" | "It was not until the third week when Dr. D….. S…. discussed autonomous vehicles that everything clicked into place"<br>"I had to try to understand and implement an aspect of cybersecurity into my course"<br>"At times I felt overwhelmed by the sheer volume of information provided, but everyone was happy to help me break it down and understand it"<br>"It also really opened my eyes to the growing need for cybersecurity professionals to protect the information and identity of individuals and businesses which use the internet or any technology at all" |

| | | | |
|---|---|---|---|
| Gain inspiration for technology use | “To bring something new to a class that has a technology background”<br>“Learn new programming techniques to share with them as well”<br>“More technology applications in my classroom”<br>“To get a better understanding of how to safely and effectively use technology in the classroom”<br>“Learn new ways to implement technology into the classroom”<br>“Another element of relevance to the outside world” | “Anything I can use in my classroom is awesome” | “I used hands-on activities to teach the kids what ciphers are and how they connect to cyber security”<br>“The students will have completed units on drafting, building algorithms, coding, types and uses for robots, flowcharts, mechanical systems, automated systems, and programming”<br>“We will utilize a Cybersecurity card game titled, “*Cyber Threat Defender*” and the popular AR game, “*Pokemon Go,”* as well as VR Oculus Rift games.”<br>“I am excited to help my students make these connections between a new avenue of learning and Game Design”<br>“Through my cybersecurity unit, they will understand the different types of threats that hackers pose on Point of Sales systems, and they will learn practical ways to protect the information of their company and their clientele”<br>“I developed a cyber security unit for my Introduction to Culinary Arts course” |
| Challenges to technology use | **Topic too complex**<br>“the specific topic I was selected for may be too complex for both me and my students”<br>“The level of the courses has to be appropriate for more advanced topics to be included”<br>“I'm concerned that it might not seem relevant to students”<br>“Much of my instruction is more Algebra related than programming”<br>**Time**<br>“Time is my main concern. I only have three hours and forty minutes a week to teach and explain a huge amount of material” | **Topic too complex**<br>“My subject is a foundational skill for the research - very difficult to bring the research down to Algebra level.”<br>“Being able to take a complex programming topic and converting it into a HS Project based physics course.”<br>“Comparing the level of the project I was assigned to the level of the class I teach there is a vast difference in both topics.”<br>“My students aren't programmers, coders, or computer scientists. They'll be able to do only so much with cybersecurity/steganographic principles.”<br>“This is going to make it very hard to try and bring in the idea of Quantum Cryptography.” | |

| | |
|---|---|
| “One of the biggest challenges I might face is time”<br>“I imagine that the typical issues will arise, too much information and too little time to deliver the content.”<br>“I am afraid that my lessons may not be timed correctly or appropriate for my group of students”<br>**Access to materials**<br>“students ability to access the required materials. Many are low-income.”<br>“finding the equipment to use for my classroom”<br>**Administrative support**<br>“Following district/state required lesson objectives and including RET learned topics”<br>**Lack of confidence with technology use**<br>“I'm not real good with computers, and the discussion of coding makes me a little nervous.” | “The actual research did not fit in to my subject areas as it was way above their knowledge level and had no state standard that matched up to it”<br>“The specific research is not applicable to my classroom”<br>“That the math is very high level and a lot of it will be lost in translation to my students.”<br>“The research with the grad student has very little application to what I am teaching or will be teaching”<br>**Time**<br>“Finding the right time to implement it”<br>“Just finishing all the preparation of lessons and activities.”<br>“I don't have the time in my teaching schedule/scope and sequence to implement lengthy projects and lessons”<br>**Access to materials**<br>“Cost of materials”<br>**Administrative support**<br>“I expect to have difficulty getting these topics into my syllabus.”<br>“Another issue is that since there are 20+ other instructors teaching the same topic I can't in good conscience make this material required. It will probably be spread out as bonus assignments or something like that.”<br>**Student interest/buy-in**<br>“I also worry about student interest”<br>“I won't have buy in from my students since cyber security and Geometry aren't connected”<br>“Student push back” |

A sample teacher presentation is presented in Figure 1, and a lesson sample for classroom use is presented in Figure 2. These are products from different teachers, but the technology integration is evident in both teacher artifacts.

**Figure 2.** *Sample of Teacher Presentation Poster*

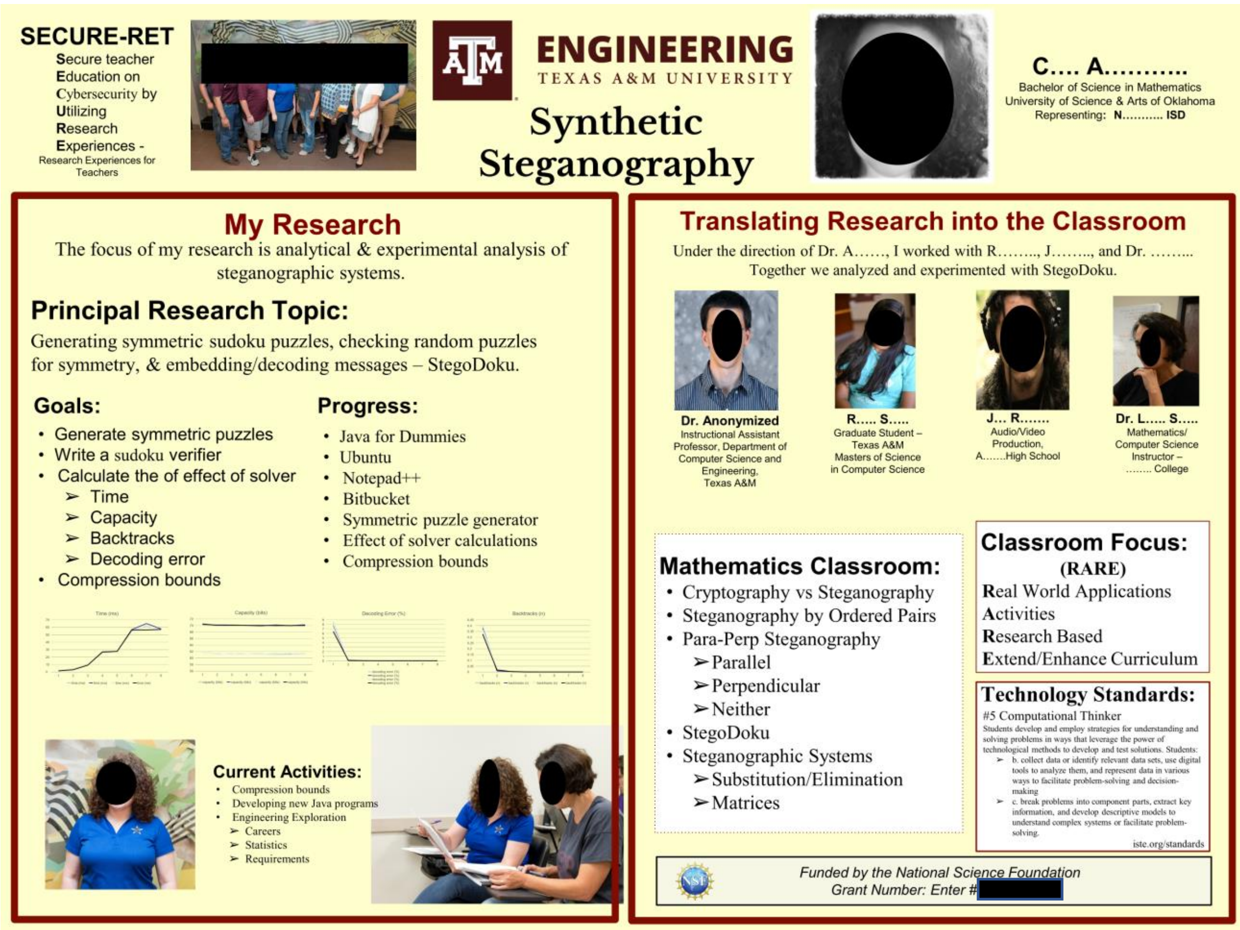


**Figure 3.** *Sample of Lesson for Classroom Use*

## Virtual Machine/Mininet Tutorial

**Operating System** – the Software that supports a computer's basic functions, such as scheduling tasks, executing applications, and controlling peripherals (Ex Printer, WebCam)

**Virtual Machine (VM)** – A virtual Machine is a Software Computer (Computer running within your normal computer) It allows you use other operating systems on 1 computer. The virtual machine will be running a different operating system.

**Terminal** – a command line executable program that allows you to access folders, run programs, and explore your computer. You must use a string of formally known characters to initiate and action on a command line terminal.

**Mininet** – a program run inside of a terminal that allows you to set up a virtual network. This allows you to manipulate a network without having all of the equipment a normal network would have to have. A normal network would have some of the following; Multiple Client/Host Computers, network switch(s), router, modem, network controller, DHCP Sever.

**IP Address** – a Unique string of numbers sepereated by periods that identifies each computer using the internet protocol to communicate over a network. (Ex 10.0.0.1 or 192.0.0.68)

**Controller** - is a hardware device or software program that manages or directs the flow of data between 2 or more entities. The controller we will use is a software program that controls the network that we will manipulate.

**Module 1: Using a Virtual Machine to Run Mininet on a Terminal.**

1. Open the Oracle Virtual Machine
   a. This may take some time. Be Patient
   b. A webpage and a Terminal will open when the VM is done booting up
2. Type in the following commands **EXCATLY** into the terminal.

ubuntu@sdnhubvm:~$: ls (This is what the first command will look like.

a. $ ls –this will show a list of files/folders/executable programs
b. $ cd secure – this will move you inside of the secure directory
   i. Should now look like this - ubuntu@sdnhubvm:~/secure$
c. $ ls – this will show a list of files inside of the secure directory.
   i. What folders do we have inside of the secure$ directory?
      1. ____________ ____________ ____________
d. $ sudo mn – this will create a Mininet basic network with the following;
   i. 2 Hosts (____, ___)
   ii. 1 Switch (____)
   iii. 1 Controller (____)

Draw a basic TOPOLOGY of this basic network below

The command prompt changes here and you should see mininet>

e. Mininet>xterm h1 – opens a new h1 terminal.
   i. This allows you to pretend you are now h1 (host 1 = computer on part of the network)

From Node:h1 "Node: h1" root@sdnhubvm:~/secure#

f. # ping 10.0.0.2 – this will send a ping (packet of information) to h2 IP address **CNTRL+C** will stop the ping
   i. How many bytes ________
   ii. Time for first packet ________
   iii. Time for last packet ________

   10.0.0.2 Ping Statistics

   iv. ___ Packets Transmitted, ___ Packets received ___%packet loss, time ___ms

From the Original Terminal ~/secure$

Field observations and informal teacher-researcher and teacher-teacher conversations also corroborate the emerging themes from the reflections and open-ended survey responses. The teacher reflections also provide us with additional thick description of why and how teachers chose the unit they wanted to teach using the skills they had learned from the RET (Hays & Mckibben, 2021; Lincoln & Guba, 1986).

**Results**

When the teachers wrote about professional learning in their pre-program survey, they were talking about individual learning experiences, but many of them wrote about collaboration being a meaningful element of learning. The PD seems to have impacted some teachers' views of their professional learning experience negatively, since they feel the content was too difficult for their level of expertise. Also, the PD did not seem to give them as much inspiration for technology use as they had initially envisioned. Personal interest and gaining confidence were the two themes that remained positive at the end of the PD. At the end of the PD, the teachers were able to create lesson plans and units and integrate some part of their RET experience into classroom use. They successfully presented their units in the form of a poster. This activity might have generated feelings of confidence and fueled their personal interest, which was reflected in the post survey responses.

The post program reflections add to this finding, because many teachers write about becoming unsure and frustrated at the beginning of the PD, but slowly gaining confidence by the end of the PD. One teacher even writes that they felt like they had "imposter syndrome" because of the difficulty level of the materials, while another wrote "Visiting the lab where the physical work was being done on the vehicles was tremendously helpful.  It helped me develop a vision for my unit and student learning". Most teachers credit the teacher educator from the College of Education as being a very significant factor in their confidence building when she "provided wonderful curriculum support and cleared misunderstandings". One teacher wrote, "these activities help link cybersecurity concepts with seventh grade math curriculum to get the students interested in the possible career path in the future", and another wrote that it took her three weeks but she found her way, "While researching how to teach cybersecurity inside the classroom, I found the card game *Cyber Threat Defender* which helps students better understand the dynamics of a hack, or cyber threat". Teacher confidence improved and they were able to integrate their learning into their deliverables (lessons for classroom use).

**Discussion**

The main goal of the current study was to understand how an immersive, intensive technology-rich PD experience would impact teacher perceptions of technology use. Two different researchers collected the quantitative and qualitative data, and data collection was done in a parallel manner, and then integrated when the write-up for the two types of data were prepared (Teddlie & Tashakkori, 2009). When both data sources were integrated, a more accurate picture of the picture of the RET and its impact on teacher technology integration emerged. Teacher perceptions are important because they are the indicators of changing teacher beliefs (Francom, 2020). Therefore, teacher perceptions of barriers to technology use could shift to where teachers perceive fewer barriers than before. While there were no statistically significant differences between the pre and post program responses, several interesting themes emerged from our analysis of the qualitative data. At the pre-program stage, most teachers perceived the technical content of the PD (computer hardware and software use related to cyber-security) as being difficult. Contrary to expectations, at the post-program stage, a larger number of teachers reported feeling the content was too difficult to teach to their students. As opposed to linear models, a complex model of teacher learning suggests that the teachers adapt the content of the PD according to their previous knowledge and experience (Fore et al., 2015). This could possibly explain why teachers entering the PD with a preconceived notion of how the content would be useful to them in their classroom, should continue to feel that way even when the content has been simplified. Another explanation could be teacher expertise on the specific technology in this PD. Most teachers in the PD started out reporting little or no knowledge of the cybersecurity technology tools. This self-reported lack of expertise might have impacted their perceptions and beliefs (Backfish et al., 2020). Therefore, teacher learning might be motivated more by teacher perceptions and prior beliefs than by professional knowledge.

Teacher learning can be said to consist of three subsystems (Opfer & Pedder, 2011). The teacher, the school system and the learning activity. In order to account for changes in teacher learning, each subsystem and its dynamic interaction with the others must be considered equally important. Teachers bring in their own prior knowledge, interest and beliefs into the PD, and their learning is shaped by all these plus other components. While most of the teachers in this PD were from STEM backgrounds, some were not. During informal conversations and in our field observations, we found the non-STEM teachers struggled with integrating technology more so than STEM teachers. Because of the significant pedagogical differences among subjects, the non-STEM teachers may have been at a disadvantage (Kennedy, 2016). Also, teachers need to perceive the utility of the PD in order to integrate technology into their teaching practices (Backfisch et al, 2021). Typically, a PD that meets outside of a classroom might not be able to facilitate enactment of the PD inside the classroom. Therefore, despite clearly defined objectives for the final output of the PD, there were impediments to outcomes of teacher learning and engagement.

In post program responses, teacher inspiration for using technology shows a large increase. Also, teacher artifacts and lesson plans showed the researchers that the teachers worked in teams and gained skills over the course of the six-week PD. Providing teachers with high quality learning experiences, and guiding them towards student-centered teaching practices should be rooted in the complex system of schools and the fabric of dynamic relationships (Fischer et at., 2018). Perhaps the teacher educator instinctively accounted for complex relationships between teachers and their learning, thereby helping teachers to work collaboratively and bridge the gap between their research experiences and practice.

We argue that while the PD seemed to be a good fit for some teachers, it was not so for others. Evidence from the current study suggests that technology-related teaching skills are separate from teachers' individual digital skills, and the former is essential for effective technology integration (Sailer et al., 2021). Individual digital skills may not have been taken into account before recruiting participants for the study. Once again, we circle back to a complex interplay between informal and formal technology knowledge, pedagogical knowledge, and content knowledge. The findings of the current study identify several avenues of future research and practice.

The responses of the teachers seem to suggest that while they came into the PD hoping for a high level of professional learning, they left the PD somewhat less motivated. This finding leads researchers to wonder if the developers and facilitators of the this specific RET failed to balance their own goals and ideals with those of the participants (Kennedy, 2016). One of the common complaints of the teachers during the PD was that their research guides were out of touch with the real world. This fact once again, brings into relief the complexity of teacher learning and teaching practices.

## Conclusion

### *Limitations*

The current study was conducted using a convenience sample, which poses a threat to the external validity of the study. The findings from this study should be generalized with caution. As a rule, patterns in PD studies are hard to detect because PD programs can be very different from each other (Kennedy, 2016). Secondly, we did not examine the differences between the participants perceptions from one year to the next. Another limitation of the current study is that it did not track the changes in teaching practices in the classroom. However, access to classroom observation for the participants was outside of the control of the research team. Finally, while mixed methods techniques offer many benefits to research by way of providing a deeper understanding of quantitative results, there are some drawbacks to this technique. One of the potential limitations of this technique is that findings may not converge. For instance, themes developed from informal observations could be different from teacher responses in survey questions. One set of themes must however, not be discarded or disregarded in preference to another.

### *Implications*

The implications generated for teacher education programs and teacher educators through the current study are compelling. While PD should have a direct and clear impact on teacher learning, the findings from this study suggest otherwise. Changes in teaching and learning is a complex problem, and must be addressed through multiple overlapping measures, ideas and practices (Blundell et al., 2020; Martin & Dismuke, 2017; Opfer & Pedder, 2011). Adding to the problem is the fact that there are no standardized measures of teacher learning. For example, for measuring the impact of RET PDs, each program team seems to use a different survey instrument (e.g., Blancahrd et a., 2007; Conceptualizing PD with complex teaching systems in mind would assist teacher educators, STEM researchers and teachers to form connections between concepts and practices which form connections  through the system. While we have examined the evidence from the current study through complexity theory, there still remain many more variables in the system which could be avenues for future research.  The first step in the direction of research would be to understand teacher learning as a complex adaptive system, where the relationship between input and output is non-linear (Ovens, 2017). Exploring and understanding teacher learning as a complex system could support and consolidate long-term goals of transformative learning (Keay et al., 2018). Further research is required to understand the relationship between teachers and how they learn, un-learn and re-learn from teacher PD.

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# CONCLUDING CHAPTER

The current dissertation has drawn on three studies on teacher professional development (PD) and technology integration. In this chapter, I will first provide the readers with the summary of each study. All three studies share a common thread in that they aim to identify how PD impacts teacher technology integration. I will then interpret the findings from the three studies, and provide recommendations and implications for future research and practice.

## Summary of the Studies

In the first article, I have synthesized evidence from 7 papers (20 studies), randomized control trials and quasi-experimental studies in the form of a meta-analysis. Researchers have proposed that blended learning (BL) improves student outcomes. However, there is a paucity of research that examines how blended learning in teacher PD impacts student achievement. The purpose of this meta-analysis was to analyze the impact of blended learning teacher PD on mathematics and science achievements of PreK-12 students. Robust variance estimation techniques were used to detect any effect that such a PD might have. Additionally, I examined *how* technology used in a PD might moderate student achievement. I found a small positive effect of blended teacher PD on student achievement (ES=.176, $p<.05$). This finding confirms that teacher learning as a result of PD frequently shows small gains in student achievement (Egert et al., 2018; Fore et al., 2015). Surprisingly, moderator analysis revealed surface level use of technology in PD produced a small positive effect on student achievement, indicating that transformative teacher learning was, in fact, *not* taking place.  These results also corroborate previous research on the complexity of variables associated with teacher learning and student achievement (Cochran-smith et al., 2014; Didion et al., 2019; Opfer & Pedder, 2011). In sum, while blended learning in PD did have a small positive effect on student achievement, it did not activate transformative teacher learning.

In the second article, I conducted a secondary data analysis on a large nationally representative sample of teachers (*N*=2,560) using data from the OECD database, specifically the Teaching and Learning International Survey (https://nces.ed.gov/surveys/talis/). Information and Communication Technology (ICT) is becoming more and more important in classroom instruction. While there are numerous studies on factors that impact ICT use, they do not examine the specific link of teacher PD with ICT components to classroom ICT use. Using multilevel ordinal logistic regression techniques, I examined the ICT use in PD and teacher characteristics as predictors of classroom technology use. Surprisingly, findings indicate teachers who received ICT in PD use less ICT in the classroom.  The odds of a teacher using technology decreases by approximately 67% after the teacher received ICT in PD. Additionally, the model explained very little of the variance in teacher technology use. Contrary to previous research, evidence from the current study suggests that PD might not be the most important component impacting teaching practices. As a result, many questions came up which could not be answered by the responses to the TALIS questionnaire. For example, time lapse between PD and classroom teaching (TTE 2021 paper???), voluntary vs mandatory participation in PD (McKeown et al., ), coaching and feedback during the school year (Kraft et al., 2018), and duration and intensity of PD (Desimone, 2009). The results from the second study indicate that in addition to PD and teacher characteristics, there may be several other significant factors that impact teacher learning and practices.

Research experience for teachers (RET) PD and technology integration was the focus of the third study. A National Science Foundation grant (https://www.nsf.gov/) provided funding for this university-school partnership, Research Experience for Teachers (RET) in cyber-security. In this specific type of PD, secondary teachers and faculty from community colleges were involved in research with university professors. This immersive, experiential RET was conducted by faculty from the Departments of Computer Science and Engineering, and Curriculum and Instruction. The teachers were immersed in hardware and software used in cybersecurity. The main purpose of this longitudinal study was to understand if teachers' perceptions of barriers to technology use would change as a result of the RET PD. Complex mixed-method analysis was used to examine the various sources of data. The findings indicate that teachers did not connect with the content of the RET PD, and had trouble finding ways to integrate technology into their classrooms. This suggests that teachers' personal experiences and prior knowledge should be taken into account when designing a PD (Blanchard et al., 2018). This study supports evidence from other RET research where there was no consistent evidence of the impact of RETs on teacher learning or practices (e.g., Blanchard et al., 2007; Hess et al., 2017; Southerland et al., 2016). The results from this study indicate the need for effective partnerships in continuing teacher education.

The three studies summarized above highlight the dynamic and complex connections between PD and teacher technology integration. Changes in teacher learning or technology integration practices cannot be attributed entirely to PD programs. These findings suggest a tantalizing perspective that complex teacher factors may hold the key to transformative teacher learning. A synthesis of the findings from the three studies is presented in the next section.

**Synthesis of Findings**

Taken together, these studies suggest that effective PDs are difficult to design and implement.  Teacher education research is, in fact, based on a linear paradigm that student achievement is significantly impacted by teacher quality, and teacher quality is significantly impacted by teacher education. Therefore, to improve teaching quality, initial teacher education and continuing teacher education (PD) must be improved. However, according to researchers, teacher professional learning is a complex phenomenon and must be addressed as such (Cochran-Smith et al., 2014; Opfer & Pedder, 2011). Researchers who have tried to simplify variables advise caution against oversimplification because teaching is a complex profession (Klassen & Tse, 2014). Making the task even more difficult is the fact that most large-scale research examines the effect of the PD in its entirety, rather than its separate components, making it difficult for researchers to evaluate which features work and which do not (Hill et al., 2013). There may be many reasons why teacher PD is inadequate in transforming teacher learning and practice.  In this section, I will unpack the important findings of this dissertation by synthesizing it with previous literature of PD and technology integration practices of teachers.

**Unpacking Teacher PD**

Because there is a paucity of evidence on effective PD, researchers have looked for problems within PD programs and how they are implemented. However, schools are a significant factor in the complex system that teachers are a part of, hence the clustering of teachers within schools should be taken into account when developing and delivering PDs. Westine et al., (2020) found that much of large-scale educational research has focused on student-level clusters, and largely ignored the nestedness of teachers within schools. In a recent study on how PD might improve teaching, Gore (2021) suggests one way to simplify the complexities of PD is to differentiate between the teacher and teaching. Contrary to the consensus model of PD (Desimone, 2009), she suggests that rooting PD in pedagogy, and emphasizing teacher collaboration might be an effective way to reform PD practices. Therefore, instead of approaching teacher PD and its impact on teacher quality as a linear progression, researchers might choose to use theory of complex systems. This dissertation raises the possibility that understanding teachers learning as a complex system might present researchers with a better picture of effective PD design.

Teachers are also learners in PDs, and need guidance and supervision to use new materials and learning (Didion et al., 2020). Teacher professional learning should be treated as a different construct than teaching practices. Researchers like Lefstein et al., (2020), note that teachers learn in a variety of ways, and taking teachers' informal learning into account is important in PD research. They recommend taking a more holistic view of teacher PD, which includes classroom experience and teachers' personal lives. Kraft et al., (2018), found that coaching might be an effective tool for improving teacher learning and have an impact on student outcomes, but also reported that coaching might be hard to scale up. Hill et al., (2013) urge researchers to be rigorous with designing PDs at the initial stages, with multiple groups of teachers and facilitators, and to be careful when making assumptions about teacher learning. A learner-oriented model of PD has been proposed by Sprott (2019), in which learning might occur through teacher interactions among teacher-teacher collaboration and student-teacher collaboration. In fact, much of the recent literature on teacher professional learning seems to point at a bottom-up model of PD as being more effective than the top-down model, which has been examined in the current dissertation. The PD programs studied in this dissertation were built as top-down models, beginning at the university/researcher level and filtering down to the school/teacher level. Taking each teacher's professional knowledge and interests into account before developing a PD program, or having a PD program that is easily modified to fit each teacher's needs might be the key to improved teacher and student learning outcomes.

Another problem that comes to the surface when examining teacher learning in PD is that teacher-level variables are usually self-reported, and these reports are not recorded or analyzed in any standardized formats (Kang et al., 2013). When teachers report on their learning, they must first compare their current knowledge or skills with their previous levels of understanding, which could lead to inaccurate reporting. This type of reporting can therefore provide confounding data on growth of teachers' knowledge and skills. Therefore, the key characteristics of PD need additional investigation to determine whether they should be linked to gains in teacher learning by using measures of teacher learning that are not self-reported (Copur-Gencturk et al., 2019). In most of the PDs evaluated in the three studies, this design element was not addressed, and could have led to misidentified results.

High levels of heterogeneity in PD format and program quality makes it harder to examine PD outcomes under one cohesive lens (Didion et al., 2019). For example, studies differ in design elements, in learning outcomes, outcome measures, intensity, and duration (e.g., Kinzie et al., 2015; Myers et al., 2009; Polly et al., 2018; Taylor et al., 2017; Whittaker et al., 2020). The variation in PD components, and the lack of consistent results on those variations has therefore prevented researchers from building a cohesive research base for PD.

Much of the research on PD in general is applicable to technology-rich PD. Therefore, PD programs which include a technology component may be considered a subset of PD programs because technology integration presents another level of complexity in teacher learning and teaching practices. The following section presents the synthesis of evidence for PD which include technology components.

**Unpacking Technology Use in Teacher PD**

The problems of variation in PD components become more significant when technology use is a part of the PD. Even when many components of PD are similar, technology use consistently varies from PD to PD (e.g., Blanchard et al., 2007; Ozalp, 2014; Hess et al., 2017;

Saka et al., 2013; Salzman et al., 2016). This heterogeneity adds another level of difficulty for researchers when they attempt to establish general principles of effective technology use in PD. Therefore, where technology in PD and its effect on teachers is concerned, divergent findings are a norm rather than an exception, as is evident in the studies included in the current dissertation.

There are several other possible explanations for the confounding results that often plague research on technology-integrated PD. The lack of high-quality large-scale studies emerge as one of the important reasons behind the lack of consensus on technology in PD. For example, WWC standards of quality could not be met by any of the studies reviewed in this dissertation. Additionally, most RET studies, though funded by NSF, cannot be considered large-scale nor high-quality (WWC, May 2021). This problem was encountered multiple times when studies were analyzed for the current dissertation.

Teachers attitudes towards technology and perceptions of technology might have a large impact on their technology use (Adov, 2020; Bruggeman et al., 2021; Francom, 2020; Leifshitz, 2020). Attitudes and perceptions are difficult to measure because they are usually self-reported, and therefore non-standardized. In fact, researchers have even suggested that teacher perceptions of technology, and not professional knowledge dictate technology integration (Backfisch et al., 2020). PD programs that offer content and pedagogy that is personally relevant to teachers might impact teaching practices (Blanchard et al., 2017; Southerland et al., 2016). While the secondary data analyzed in the current dissertation did not illuminate researchers on relevance of PD for teachers, the RET study found evidence to support this finding. The teachers did not find the content of the PD relevant for their purposes, and no significant changes in teacher perceptions were detected.

Significant changes in student learning might occur even when transformation of teacher technology knowledge did not occur (Blanchard et al., 2018). However, very few studies examine the effect of technology PD on student achievement (Blanchard et al., 2017). Also, when a significant impact of teacher PD on student achievement is detected, the effect is usually small, leading researchers to theorize that even large changes in teacher learning may lead to small changes in student learning (Fore et al., 2015; Egert et al., 2018). In the current dissertation, I found that PD does not lead to transformative learning, even when it may be immersive and intensive.

**Conclusion**

Reviews of PD research regularly report that it is "underdeveloped and undertheorized" (Mayer, 2021, p 128). Many unrelated small-scale research studies have provided insight into localized teaching practices, but they are unable to produce large data sets that might inform policy. In other words, PD research lacks the systematic knowledge base that influence research and practice in many other fields. In fact, it is difficult to come up with such a base of knowledge for PDs because they present researchers with a dynamic system that is changing and adapting continually. What PD developers need to recognize is that teacher learning is a complex and dynamic process which requires a variety of different pathways to be effective.

While teaching is recognized as a profession, teachers are not given the same affordances as other professionals. While other professionals like lawyers and doctors are able to draw upon best knowledge and practices for professional learning, teachers are not. PD programs are designed by teacher educators and researchers who are no longer in the teaching field. Providing personalized PD tailored to the needs of each individual teacher might be an answer to the problem. While this would suggest a bottom-up model of PD, where the smallest unit of learning should be a school, not all schools are equipped with the resources to develop and deliver their own individualized PD.

Education technology is often held up as a solution to problems in student achievement, and teachers are held accountable when technology fails to deliver. However, the preparedness of teachers to teach with technology usually does not take into account the teacher's needs, and is designed and planned by others. This misalignment of technology education with technology needs of the teachers has divergent findings in research on technology use in PD. In fact, the lack of differentiation in teachers' technology education has led to potential unintended consequences, where teachers start developing barriers to technology use. Researchers and teacher educators need to have a more nuanced and thoughtful discussion about the relationship between technology and teaching. Decomposing the constructs of teacher learning with technology might be the first step towards such effective teacher PD.

**Recommendations**

Some recommendations for researchers and practitioners are listed below. Teachers should actively participate in their learning, and should be stakeholders in PD development. Teachers should be positioned as agents of reform rather than objects of reform. PD should focus on quality of experiences rather than intensity and duration. New knowledge takes time to assimilate, therefore PD time must be utilized wisely to aid transformation in teacher professional knowledge. Large-scale PD studies should be designed and implemented to establish a systematic knowledge base, where data on teacher learning outcomes is linked to data on student learning outcomes. Such databases must be made available to stakeholders in PD and teacher learning processes. Standardized measures of teachers professional learning outcomes need to be put into place. Establishing learning objectives and measuring teacher performance on those objectives should be a crucial step towards evaluating PD programs. Evaluation of PD programs requires methodological clarity and standardized measures. Qualitative and mixed-methods research inform practice and provide deeper understanding of teacher learning and PD programs, but they need to evolve further to provide approaches for developing a systematic knowledge base.

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## IMPACT OF BLENDED LEARNING IN TEACHER PROFESSIONAL DEVELOPMENT ON STUDENT ACHIEVEMENT: A META-ANALYSIS

Blended learning (BL) is a teaching technique utilized to enhance student learning experiences and outcomes, and is defined as a mix of face-to-face and online learning (Graham, 2013). BL has gained popularity over the years and many researchers are pursuing ways and means to define and develop effective instructional practices in BL environments (Halverson et al., 2014; Halverson et al., 2017). However, Rasheed et al., (2020) have pointed out that most of the literature on BL is focused on challenges faced by students, rather than those faced by teachers. Unsurprisingly, there is a paucity of research in BL in teacher professional development (PD) as well as how BL in teacher PD impacts student achievement (Yoon et al., 2007). Approximately 7% of the studies in BL address teacher PD (Drysdale et al., 2013). Therefore, there is a lack of systematic understanding of the effect of BL on teacher learning and student achievement. Additionally, there is scant research on how BL used in teacher PD influences student achievement. The current meta-analysis therefore, seeks to examine the evidence of effect of BL in teacher PD and its impact on student achievement. This study also seeks to investigate the manner in which technology use in teacher PD catalyzes student learning. By synthesizing the research outcomes on what is currently known about BL and how technologies are used in BL teacher PD, this meta-analysis makes an important contribution for decision makers such as teacher educators and policy makers.

The current meta-analysis adds to the current knowledge base in three important ways. First, the current meta-analysis is limited to studies from 2000 to 2020 because computer-mediated learning environments have evolved greatly in the last two decades (Spanjers et al., 2015). Additionally, previous meta-analyses have not focused on *how* technology is used in BL learning environments. The current meta-analysis uses the ACI (Active, Constructive, Interactive) framework (Chi, 2009) to examine the *how* technology is used in the BL environment. Third, and most importantly, this study captures the impact of BL teacher PD on student learning, an outcome not addressed in previously published meta-analyses.

**Brief Review of Literature**

Much of the recent literature in BL focuses on challenges to technology integration by students more often than teachers (Rasheed et al., 2020). One such systematic review on the challenges of BL by Boelen's et al., (2017) found evidence to suggest that technology integration in BL was done only at the surface level, during introductory sessions, and that most students did not utilize the technology to the full extent. Additionally, an emphasis on differentiated learning was found in very few studies. However, BL seemed to be effective in monitoring student progress. A systematic review by Phillipsen et al., (2019) examined important elements of online and blended PD and why they were important. They found that PD duration, context, teacher reflections on the PD, and having the teachers evaluate the positive impact of PD were important components of such PD programs. Additionally, establishing a link between PD and student learning was also important. Neither of the above reviews focused on teachers or teacher PD.

Recent reviews that have focused on teacher learning are discussed in the section below. In a systematic review, Gamage and Tanwar (2017) looked for evidence of effectiveness of teacher training strategies that impacted technology use. The key to the success of the strategies seemed to lie with the teachers' acceptance of the technology or strategy. Teachers' perceived usefulness of technology was found to be twice as important as perceived ease of use, and facilitating teachers to use technology had a positive impact on its effective use. In the same vein, Rasheed et al., (2020) found evidence from 30 studies that negative perceptions of teachers on technology use, and lack of training, impact technology use.

In addition to these systematic reviews, the effect of BL or blended and computer mediated learning on learning outcomes and student satisfaction has been examined in six recent meta-analyses: Bernard et al. (2014); Means et al., (2013); Schmid et al. (2014); Spanjers et al., (2015) and Tamim et al., (2011). These meta-analyses found small to medium positive effects for student learning outcomes. Sitzmann et al. (2006) found a medium effect on procedural knowledge based on a small sample size (six studies). Results were less consistent for student satisfaction and reactions. The effect sizes of the meta-analyses can be viewed in Table 1. It should be noted that none of these recent meta-analyses address BL in teacher PD.

**Table 1.** *Average Effect Sizes for Recent Meta-analyses of BL on Student Achievement (adapted from Spanjers et al., 2015).*

| **First author, date** | **Participants** | **Average effect size** |
|---|---|---|
| Bernard et al., 2014 | Higher education | +0.35 *(student achievement)* |
| Means et al., 2013 | Higher education and secondary education | +0.35 (*student achievement*) |
| Tamim et al., 2011 | Primary, Elementary, Postsecondary | +0.33 (*student achievement*) |
| Schmid et al., 2014 | Postsecondary | +0.27*(student achievement)* |

| | | |
|---|---|---|
| Spanjers et al., 2015 | Higher education | -0.01*(average of objective measures, subjective measures, satisfaction, investment evaluations)* |
| Vo et al., 2017 | Higher education | +0.385 *(student achievement)* |

**Theoretical Perspective**

For this meta-analysis, we use the theoretical framework for learning activities developed by Chi (2009) which differentiates learning activities on three levels – active, constructive, and interactive. We used this framework to develop the structure of our coding scheme. We used this theory to guide our coding scheme because we were interested in exploring the use of technology in teacher PD. This theory separates the different uses of technology based on its cognitive use. Active learning signals the performance of an activity while learning. An example of active learning in a computer mediated environment is searching, underlining, summarizing, selecting, copying and pasting (Chi, 2009). Constructive learning takes place when students generate a product of new information. In online learning, creating new information from previously established information is practiced by making concept maps, comparing and contrasting, making analogies, writing reflections, and so forth (Chi, 2009). The third level of learning, interactive, has been described as dialogues between teacher and student or between peers. In the case of computer-based learning, interactive learning is generally experienced through intelligent tutoring systems, and thus involves a tutor. Hence, through the use of the active-constructive-interactive framework, we differentiate the use of education technology used in teacher PD programs. We incorporate this framework to understand how one level of activity might have a different impact on student outcome as compared to other levels.

## Purpose of the study

The impact of math, science and reading PD has been synthesized in the past few years (e.g., Blank & Alas, 2009; Didion et al., 2020), but there are not studies that synthesize the evidence from blended PD programs and how they impact student achievement. There has been an increase in studies that examine the effects of PD on student outcomes. Therefore, there is a need review evidence of blended PD on student achievement. Additionally, there are no syntheses on how technology use in PD can impact student outcomes. Therefore, it is the purpose of this study to examine the impact of blended PD on student outcomes, and to examine study characteristics and intervention characteristics as moderators of student achievement.

## Research Questions

**RQ1:** What is the relationship between blended learning professional development and PreK-12 student achievement in mathematics and science?

**RQ2:** How do study characteristics (i.e., study design, grade level, content area, outcome measures) moderate the effect of blended PD on student achievement?

**RQ3:** How do intervention characteristics (i.e., *how* technology was used in PD, implementation supports offered to teachers through the school year, PD intensity, fidelity of implementation) moderate the effect of blended PD on student achievement?

## Method

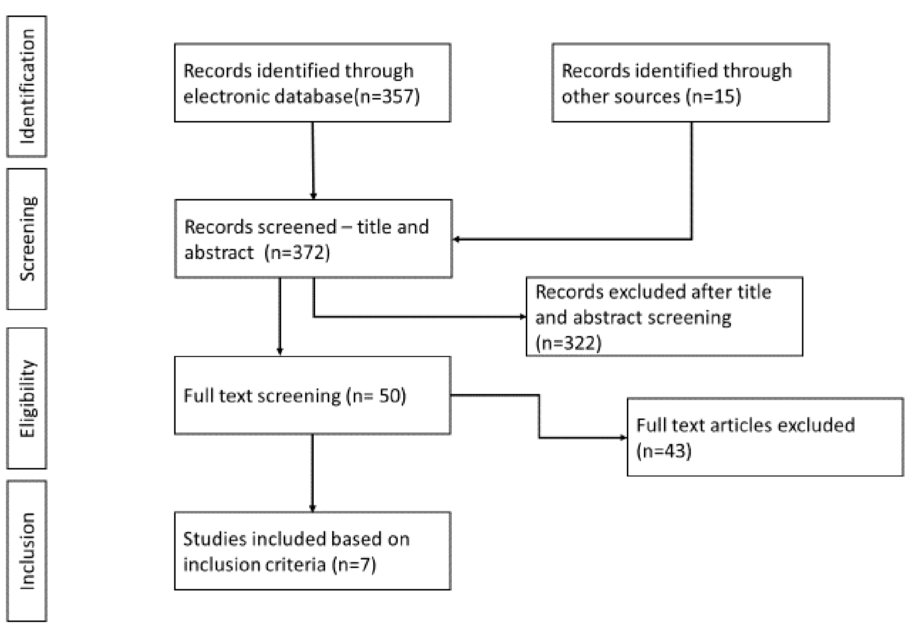
### *Search Procedures*

Our database search included Eric, Education Source, ProQuest Dissertation and thesis, and Professional Development Collection. We also performed manual searches of relevant journals (*Teaching and Teacher Education, Journal of Teacher Education, Computers & Education*, *Journal of Research on Educational Effectiveness*, *Journal of Research in Science*

*Teaching*, *American Education Research Journal*, *Educational Researcher*, *Journal of Teacher Education*, *Teaching and Teacher Education*, and *American Journal of Education*). We also searched the What Works Clearinghouse, Teacher Excellence section for relevant studies. Finally, the references from all included studies were analyzed and pertinent articles were located. We emailed authors when the articles could not be found online or through library resources, but most of the authors contacted did not respond to our queries. Appendix A contains the search terms utilized in this meta-analysis.

Our initial database search yielded 357 articles, and our hand search yielded 15 articles. After title and abstract screening, we were left with nine articles. Upon filtering the articles for full text, we were able to find seven that provided us with the relevant information and data analysis. The details of this process can be viewed in Figure 1.

**Figure 1.** *Prisma Diagram*




### *Inclusion and Exclusion Criteria*

We used the following inclusion criteria for selecting the studies in the current analysis: (a) must include PD for teachers that utilizes a blended learning model, (b) must describe both the PD and the technology element(s) used for blended learning, (c) The study must include student achievement scores in math or science, (d) PD was provided to teachers of Pre-K to 12, (e) teachers included taught math and/or science, (f) be quasi-experimental or experimental in design, (g) published in English, (h) be published between 2000 to 2020, and (i) contain the data needed to calculate an effect size. Studies were included regardless if they were peer reviewed or their geographical location.

We made attempts to contact researchers to obtain needed missing raw data, but did not succeed ($n$=3). Furthermore, we excluded studies that compared purely online environments to face-to-face learning, because our intentions were to examine a BL environment, which requires a component of face-to-face learning as well as online learning. In essence, we included studies that gave us some description of how technology was used for blended learning to enhance a traditional learning environment for teacher audiences.

***Coding Procedures***

The first author developed the coding scheme by identifying demographic codes and developing codes relating to the theoretical framework. The study features were coded for study characteristics and intervention characters (see Table 1 for details). The first author trained two researchers on the coding scheme. Agreement during training was 85%. Each researcher coded three (50%) randomly selected studies individually (inter-rater reliability was 95%). Disagreements were resolved through discussion and final agreement was 100%. See Table 2 for codes and definitions of moderators.

**Table 2.** *Codes and Definitions for Study and Intervention Characteristics (n=7, k=20, #ES=77)*

| Moderators | Code | Definition | *k* | #ES |
|---|---|---|---|---|
| Study design | RCT=1 | RCT – Random Control Trial | 7 | 21 |
| | QED=2 | QED – Quasi Experimental design | 13 | 56 |
| Grade level | Primary=1 | Primary – PreK | 4 | 22 |
| | Elementary=2 | Elementary – K-6 | 12 | 44 |
| | Secondary=3 | Secondary 7-12 | 4 | 10 |
| Content area | Math=1 | Content area taught and assessed | 14 | 64 |
| | Science =2 | | 6 | 13 |
| Outcome measures | Standardized = 1 | Measures used to assess the impact of the intervention. Measures designed | 3 | 7 |
| | Researcher designed=2 | by researchers; the outcome measure is researcher designed. District/State test is standardized. | 17 | 70 |
| Technology use in PD | Active=1 | Active – learn to use technology | 15 | 52 |
| | Constructive=2 | Constructive – analyze and synthesize knowledge from technology | 5 | 25 |
| | Interactive=3 | Interactive – technology interacts with teacher to construct knowledge | 0 | 0 |
| PD duration in hours | >24 hours = 1 | Each day of PD was equivalent to 6 hours. Total time was calculated by | 18 | 65 |
| | 1-23 hours =2 | adding together the days and hours spent in PD. | 2 | 12 |
| Implementation | Yes=1 | PD supports offered through school | 15 | 63 |

| | | | | |
|---|---|---|---|---|
| Support | No=2 | year, either online or face-to-face | 5 | 15 |
| FOI | Reported as high=1 | Fidelity of Implementation: The degree to which an intervention is delivered as intended. Level of FOI is reported as specified by the researchers of the specific study. | 5 | 15 |
| | Reported as low=2 | | 1 | 1 |
| | Not reported/ not specified as low or high=3 | | 14 | 60 |

***Computing effect sizes***

We calculated Hedge's *g* using the concept of standardized mean difference (Hedges, 1981). $\tau^2$ was calculated at ρ=0.80, and sensitivity analysis at ρ=0.20 to ρ=0.80 showed that our findings were robust across estimates. We chose $p<.05$ as our alpha value for estimating effect that are significantly different from zero. See Table 2 for included studies and effect sizes.

***Meta-analytic procedures***

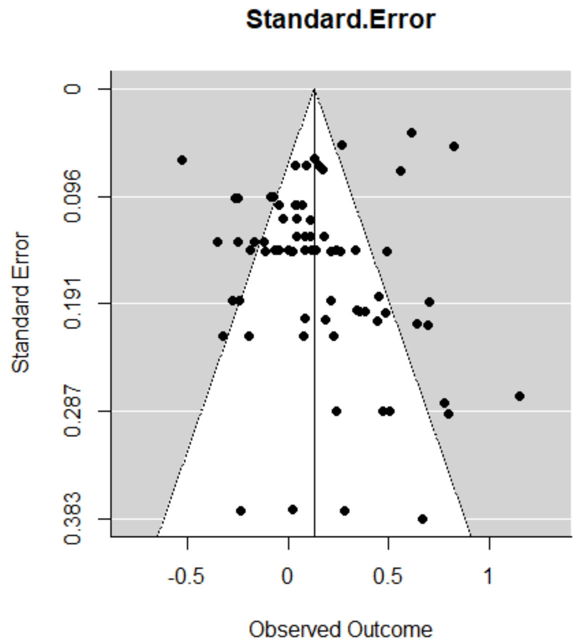
For statistical analysis of dependent effect sizes in our meta-analysis, we used robust variance estimates (RVE) to estimate the effect sizes. This approach integrates multiple correlated effect sizes within a study instead of using one single effect size or calculating their averages (Hedges, Tipton, & Johnson, 2010; Tanner-Smith & Tipton, 2014). In this way, we have accounted for correlated effect sizes that may arise if the included studies are from the same research team, laboratory, or publication. First, we estimated an intercept-only model across the 77 effect sizes (see Table 3) yielded by the seven studies using the R package Robumeta (Tanner-Smith & Tipton, 2014). The Robumeta package calculated the estimates of heterogeneity ($I^2$- chance variance between-study, and $\tau^2$ – true variance in effect sizes).

Second, we included moderators in the meta-regression models. While one regression model which includes all moderators is preferable, we did not adopt this approach, because results were not interpretable due to restricted degrees of freedom. Therefore, each moderator was examined in a separate RVE meta-regression model, where each moderator was entered as a predictor. The results are interpreted with caution, because there could be potentially confounding effects of the other moderators. Sensitivity analysis across each model (using $\rho$=0.20 to 0.80) yielded no meaningful differences across models, thereby indicating robust findings across the above stated estimates of $\rho$.

***Publication Bias***

A funnel plot was constructed to visually examine any asymmetry in the distribution of standard errors and effect sizes (see Figure 2). Asymmetry in the funnel plot suggested that publication bias was likely. Secondly, an Egger’s test (Egger et al., 1997) was conducted which confirmed our visual findings ($p$=0.033). Therefore, there is statistically significant ($p<0.05$) evidence that publication bias exists in our sample of included studies.

**Figure 2**. *Funnel Plot*




**Results**

In this section, we will first report the results of the main effect. Then we will report the results from the moderator analysis (study characteristics and intervention characteristics). Table 1 provides the results for the main effect and moderator analysis. Table 2 is used to report effect sizes from each study.

***Main Effect***

The overall estimate of 77 effect sizes in the unconditional model (without moderator variables) was 0.149 (SE=0.061, 95%, CI = 0.021 – 0.277) with a *p*-value of 0.025. The value of $I^2$ suggests that 99.06% of the between-study variation was not due to chance, and $\tau^2$ suggests that the true variance in the effect sizes is 0.04 (see Table 1).

***Moderator analysis***

**Study Characteristics.** Among study characteristics, study design, content area, and grade level were not significant moderators of the effect of BL teacher PD at a 0.05 level. However, outcome measure (researcher-designed measures) yielded the effect size 0.145

(SE=0.063, 95%CI = 0.014 - 0.276, $p$ = 0.032).

**Intervention Characteristics**. Active use of technology showed a small, significant effect of 0.156 (SE=0.071, 95%CI=0.004-0.308, $p$=0.046). PDs that lasted more than 24 hours (3 days) also contributed a significant effect of 0.157 (SE=0.069, 95%CI=0.013-0.302, $p$=0.035). Fidelity of implementation was a significant moderator when it was *not* measured or specified as low or high, and yielded an effect of 0.125(SE=0.056, 95%CI=0.004-0.245, $p$=0.043). Implementation support offered to teachers did not yield a statistically significant effect size (see Table 4).

**Table 4.** *Main Effect and Moderator Analysis of Blended PD on Student Achievement*

| | | Effect size | SE | 95% CI | *p* | *df* | $I^2$ | $\tau^2$ |
|---|---|---|---|---|---|---|---|---|
| Main Effect | | **0.149** | 0.061 | 0.021- 0.277 | **0.025** | 18.4 | 99.067 | 0.038 |
| Moderator | Code | Coefficient | | | | | | |
| Study design | RCT | 0.238 | 0.131 | 0.128 - -0.098 | 0.128 | 1.99 | 99.030 | 0.040 |
| | QED | 0.106 | 0.064 | 0.121- -0.032 | 0.121 | 1.95 | | |
| Grade Level | Primary | 0.016 | 0.079 | -0.236-0.267 | 0.857 | 3.0 | 99.13 | 0.05 |
| | Elementary | 0.159 | 0.082 | -0.023-0.340 | 0.081 | 10.58 | | |
| | Secondary | 0.272 | 0.171 | -0.274-0.818 | 0.210 | 2.98 | | |
| Content Area | Math | 0.107 | 0.061 | -0.021-0.236 | 0.096 | 16.08 | 99.003 | 0.040 |
| | Science | 0.339 | 0.149 | -0.062-0.740 | 0.080 | 4.27 | | |
| Outcome Measures | Standardized | 0.195 | 0.270 | -1.486- 1.877 | 0.567 | 1.46 | 99.072 | 0.038 |
| | Researcher designed | **0.145** | 0.062 | 0.040- 0.276 | **0.032** | 17.42 | | |
| How technology was used | Active | **0.156** | 0.071 | 0.004-0.308 | **0.046** | 13.50 | 99.093 | 0.043 |
| | Constructive | 0.136 | 0.136 | -0.239-0.510 | 0.371 | 4.0 | | |
| PD duration | More than 24 hrs | **0.157** | 0.069 | 0.013-0.302 | **0.035** | 16.0 | 99.107 | 0.044 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Less than 24 hrs | 0.099 | 0.054 | -0.583-0.780 | 0.317 | 1.0 | | |
| Implementation support offered | Yes | 0.096 | 0.061 | -0.036-0.227 | 0.140 | 13.76 | 99.092 | 0.039 |
| | No | 0.325 | 0.166 | -0.141-0.792 | 0.122 | 3.71 | | |
| Fidelity of implementation | Reported as high | 0.097 | 0.153 | -0.908-1.260 | 0.556 | 3.77 | 98.850 | 0.031 |
| | Reported as low | 0.612 | 0.000 | | | | | |
| | Not reported/specified | 0.125 | 0.056 | 0.004-0.245 | **0.043** | 13.12 | | |

*Note*. *SE* = standard error; CI = confidence interval; *p* = significance; df = degrees of freedom, Q = test for homogeneity of effect sizes; $I^2$ = measures of effect size variability; $\tau^2$ = between study variance; *n* = 7; *k* = 20; ρ= .80. In the current RVE model, ρ = 0.80 is used as an estimate of between-study variance. For *df*<4, results should not be trusted. Statistically significant (*p*<.05) values are bolded.

## Discussion

The aim of the current study was to explore the relationship between BL in teacher PD and the impact on mathematics and science student achievement. Results show that BL teacher PD does have a small significant effect on mathematics and science student achievement (ES = .149, p=.025). An effect size, in essence, determines the to which our findings are different from the null hypothesis. Our finding supports previous research that PD can help improve student outcomes, but only to a small extent (Hamilton et al., 2003; Fore et al., 2015). Another explanation for this small effect could be that while PD programs might have produced significant teacher learning, the same learning did not translate into teaching practices and instructional changes (Fore et al., 2015). According to scholars, effect sizes must be interpreted with caution because the relevance of the findings are more important than the number (Kraft, 2020; Bakker et al., 2019). However, the variation of effects in the study are considerable, which confirmed the requirement for moderator analysis.

We measured the impact of study characteristics and found researcher designed measures yielded a small but positive effect on student achievement. Among intervention characteristics, active use of technology in PD, longer PDs (3 days or more) and FOI not being reported showed positive effects on student achievement.

It was surprising that no moderating effect of "constructive" use of technology in teacher PD was seen on student achievement. It may be that teachers are reluctant to adopt new pedagogical skills (Kennedy, 2016). PD can be effective if the teachers willingly incorporate the changes in their teaching practices (Buczynski & Hansen, 2010; Kraft et al., 2018), and research has shown that teachers who volunteer to participate in PD engage and practice what they learn differently than those who do not (Bobrowsky et al., 2001). More research is required to understand what leads teachers to benefit from surface level training (active technology use), as opposed to constructing new knowledge (constructive technology use). Additionally, there were no instances in research where an "interactive" technology was used in teacher PD.

Another interesting finding was the moderating effect of FOI not being reported or specified. It is expected that higher FOI would have a larger impact on the effect of an intervention, but in the case of the current meta-analysis the evidence did not suggest so. This puzzling fact can be attributed to the inconsistent and varied use of fidelity components in research (O'Donnell, 2008; Schaap, 2018), and that very few evidence-based frameworks exist for measuring and reporting FOI (Kaiser & Hemmeter, 2013; Stains & Vickrey, 2017). While many researchers are working towards building and disseminating such frameworks (Munter et al., 2018; Tong et al., 2019), a consensus framework for FOI is still to be established. Researchers have also found that compromised FOI can have positive impact on student learning (McKeown et al., 2019a). In other words, even when teachers do not maintain high FOI, there may be low but significant effects on student achievement. Additionally, FOI and need for adaptation and modification can sometimes contrary (McKeown et al., 2019b). Therefore, the PD programs where teachers modified their instructions according to their needs might have had a larger effect on student achievement.

The duration for PDs has been a subject for research, with different researchers advocating different time frames for duration (Didion et al., 2020; Egert et al., 2020). Our findings suggest that a longer duration for the BL teacher PD is more effective than the shorter ones (less than 3 days). Teachers need time to learn new materials (Didion et al,. 2020), and therefore longer duration of PD programs might be more effective.

## Conclusion

We explored certain aspects of the included studies as moderators, but studies can differ on many aspects. There was substantial heterogeneity in the included studies which could not be explained by methodological resolution. Additionally, there was a clear publication bias which could have affected our findings, as studies with non-significant effects may not have been published. Moreover, the existence of confounding variables cannot be ruled out. Also, none of the included studies were found in the What Works Clearinghouse (WWC) repository, and could not have been positively evaluated by the rigorous standards set by WWC.

In the future, PD developers and researchers need to design PD with interactive technology tools for the teachers so teachers can engage in practice during PD and use the technology in ways that are relevant to their curriculum and student body with experts to facilitate and guide that practice (Ball & Cohen, 1999). The current study therefore, brings into focus the urgent need to develop a full picture of how BL teacher PD can benefit student achievement. Urgent research in the field of teacher learning, what variables are important to attain transformational learning, is required. Quality of teacher experiences rather than quantity might have more impact on BL teacher PD.

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## Appendix A

Keywords for search

( "Public School Teachers" OR "Elementary School Teachers" OR "Middle School Teachers" OR "Secondary School Teachers" OR "Teachers") ) OR ( teacher* or instructor* or educator* ) OR AB ( teacher* or instructor* or educator* )

AND

( ( "Professional Development" OR "Communities of Practice" OR "Inservice Education" OR "Professional Continuing Education" OR "Teacher Improvement" OR "Workplace Learning" OR "Faculty Development" OR "Inservice Teacher Education" OR "Professional Training") ) OR TI ( Professional development* OR teacher education* OR teacher education program* or teacher improvement or train* or workshop* or in-service or inservice ) OR AB ( Professional development* OR teacher education* OR teacher education program* or teacher improvement or train* or workshop* or in-service or inservice )

AND

( ( "Technology Uses in Education" OR DE "Educational Technology" OR "Technology" OR "Instructional Systems" OR "Asynchronous Communication" OR "Audiovisual Communications" OR "Computer Uses in Education" OR "Electronic Learning" OR "Handheld Devices" OR "Laptop Computers" OR "Multimedia Instruction" OR "Synchronous Communication" OR "Technology Integration" OR "Video Technology" OR "Virtual Classrooms" OR "Web Based Instruction") ) OR TI (technolog* OR ict or "information and communication* technology" or "information technology" or computer* or laptop* or tablet* or pc or pcs or i-pad* or ipad* or "digital literacy" or software or internet or online) OR AB (technolog* OR ict or "information and communication* technology" or "information technology" or computer* or laptop* or tablet* or pc or pcs or i-pad* or ipad* or "digital literacy" or software or internet or online)

AND

"Achievement Tests" OR TI (“achievement test*” or “assessment score*”) OR AB (“achievement test*” OR “assessment score*”) OR "Outcomes of Education" OR TI (student* N2 outcome* OR learner* N2 outcome*) OR AB (student* N2 outcome* OR learner* N2 outcome*)

# Appendix B

## ICC for unconditional model

Variance = .144 Level 1 residual is fixed at $\pi^2/2 = 3.29$

ICC = $\frac{Var}{(Var+residual)} = \frac{.144}{(.144+3.29)}$ = 0.0419

1. **Predicted probability from ICT in PD**

$$P(\text{uses ICT in classroom}) = \frac{\text{odds(received formal training in ICT use)}}{1 + \text{odds(received formal training in ICT use)}} = \frac{1.199}{1 + 1.199} = .545$$

2. **Predicted probability from ICT in PD**

$$P(\text{uses ICT in classroom}) = \frac{\text{odds(received ICT in PD)}}{1 + \text{odds(received ICT in PD)}} = \frac{.674}{1 + .674} = .402$$

## Variance in ICT classroom use by teachers (McKelvey & Zavoina, 1975)

```
. predict fixedpart, xb
(151 missing values generated)

. summarize fixedpart
```

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| fixedpart | 2,409 | -.5542212 | .1955631 | -.8131053 | -.4065526 |

$.1956^2/(.1956^2$+variance of level 2 random effects + level 1 residual variance)

$= .1956^2/(.1956^2+.1451+3.29)$

$=.0383/(.0383+.1451+3.29)$

$=.0383/3.4734$

$=.011$