Handbook of Research on Transforming Mathematics Teacher Education in the Digital Age

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Chapter 15
The Influence of Professional Development on Primary Teachers' TPACK and Use of Formative Assessment

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ABSTRACT

Formative assessment continues to be heralded as a high-leverage teaching practice that has empirical links to student achievement. This chapter describes the design and influences of a year-long professional development project focused on supporting primary grades teachers' with formative assessment skills in mathematics. The professional development was a blended format that included face-to-face workshops as well as classroom-based activities that were presented and facilitated through an online asynchronous format. Findings from the study indicated that teachers' enacted evidence of various aspects of TPACK, but there was variance in terms of how teachers implemented pedagogies. Implications for the design of professional development focused on formative assessment include the need to situate teachers' learning in their classroom, and provide ongoing multiple modes of support to help teachers enact formative assessment practices.

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INTRODUCTION

Formative assessment is a cyclical process that involves examining students' thinking, collecting data, analyzing the data, and then implementing instructional activities based on the data collected (Wiliam, 2007a, 2010). While formative assessment is a term used widely by educational researchers and educational leaders in mathematics, formative assessment needs to include rich assessment tasks embedded in the context of the classroom that allow teachers to better understand their students' abilities and mathematical thinking (Joyner & Muri, 2011; Wiliam, 2010).

Prior research has found that while formative assessment has the potential to positively impact students' mathematics achievement (Ringer, 2013; Wiliam & Thompson, 2007; Polly et al., 2014a), teachers often struggle with its process (Martin & Polly, 2015; Polly, Martin, Wang, Lambert, & Pugalee, 2015). At times, teachers pose tasks that are not rich or that lack rigor, and therefore do not allow an opportunity to collect valuable information about students' thinking (National Council of Teachers of Mathematics [NCTM], 2014). Additionally, it is documented that teachers struggle to carry out the subsequent steps after collecting assessment data. Collecting data without taking the next steps to make data-based decisions makes the work of assessing students relatively germane if the information collected does not inform future instruction (Martin & Polly, 2015; Ringer, 2013).

Technology has the power to facilitate the processes related to formative assessment (Beatty & Gerace, 2009; Polly, Little, & Rodgers, 2015; Wiliam, 2010). In literacy, programs such as M-Class/Reading 3D allow teachers to assess students by entering information in a web-based program while students read a passage and answer comprehension questions. The program provides teachers a summary of students' performance, tracks their progress over time, and provides instructional recommendations (Amplify, 2015). Likewise, in mathematics, programs such as *AMC Anywhere* (Didax, 2012) allow teachers to enter information in a web-based system while students solve mathematical tasks and answer questions about number sense (Math Perspectives, 2015).

This chapter focuses on professional development aimed at supporting the use of *AMC Anywhere* in primary grades classrooms. The chapter provides a description of the Assessment Practices to Support Mathematics Learning and Understanding for Students (APLUS) professional development project funded by the North Carolina Department of Public Instruction grant program and designed to support primary grades teachers in implementing formative assessment practices. We provide an overview of the professional development project and the goals of the project. We then detail how the project was revised or modified across the three year-long cohorts of implementation, and share outcomes from the project as a synthesis of our research studies. Lastly, we provide implications for the design of professional development focused on formative assessment or other high-leverage teaching practices.

BACKGROUND

Formative assessment practices in mathematics have been empirically linked to gains in students' mathematics achievement (Wiliam & Thompson, 2007; Polly et al., 2014a) as well as gains in teachers' awareness of their students' successes and struggles (Black & Wiliam, 1998; Wiliam, 2007b). Further, these gains have been observed in impoverished schools with students who chronically struggle in mathematics (Fuchs & Fuchs, 1986; Wiliam & Thompson, 2007). Recently, NCTM (2014) identified formative assessment as a high-leverage teaching practice that holds great potential to improve students' mathematical understanding.

These studies have cited that gains in student learning occur more readily when teachers carry out the entire formative assessment process (NCTM, 2014; Wiliam, 2007a). The process includes purposefully assessing students' mathematical thinking, analyzing the data, and implementing instructional activities that specifically address students' learning needs (Polly et al., 2014b). Further, formative assessment practices are only effective if they are specifically aligned to standards and if subsequent instructional activities align to both learners' needs and the concepts included in the formative assessment (Black, Harrison, Lee, Marshall, & Wiliam, 2004; Heritage, 2007).

Various technologies have been found to support formative assessment (Polly, Little, & Rodgers, 2015). For example, interactive clickers and student response systems allow teachers to pose questions and have students respond instantly using a wireless hand-held device (Beatty & Gerace, 2009; Polly, et al., 2015). Recently, internet-based tools such as Poll Anywhere and Kahoot allow teachers to gather answers and information on student performance instantaneously. In some studies, teachers learned about interactive clickers during professional development and used them in their classrooms. While student engagement increased with the use of these devices, the level of mathematical tasks and teachers' data-based decision making varied across the year (Polly, 2014; Polly et al., 2015). In one study, teachers' use of the clickers was primarily associated with lower-level, basic mathematical tasks focused on computation (Polly, 2014).

Despite the potential of technology-rich formative assessment tools, researchers who have examined teachers' use of formative assessment in mathematics using the *AMC Anywhere* internet-based tool have documented various struggles that teachers have had in attempting to implement these processes. Recently, Ringer (2013) found that teachers self-reported that both they and their students benefited from using a formative assessment tool. However, Ringer (2013) noted a number of challenges that teachers either reported or demonstrated, including uncertainty about: the purpose and use of the formative assessments, how the assessments aligned to their mathematics standards, how to balance time for instruction and assessment, and finally, how to make sense of the data that they collected. Similar findings have been found by other researchers who noted that teachers did not know how to embed formative assessment effectively into their mathematics classroom without sacrificing large amounts of instructional time (Abrams, 2007; Martin & Polly, 2015; Martin, Polly, Wang, Lambert, & Pugalee, 2016). The barriers did not focus on the use of the technology for formative assessment practices, but on the process of formative assessment in general (Polly et al., 2015; Martin & Polly, 2015).

Research suggests that in order to effectively carry out formative assessment practices, teachers need to have knowledge of mathematics, pedagogies, and students (Polly et al., in press; Ringer, 2013). We describe a process that supports teachers' use of an internet-based mathematics formative assessment tool through hybrid professional development. We also share the revisions of this project over its three years.

THEORETICAL FRAMEWORK

The theoretical framework for this study incorporates the constructs of Technological Pedagogical Content Knowledge (TPACK) and learner-centered professional development (LCPD). TPACK provides a lens to examine the intersection of mathematics and the formative assessment tool in the professional development, while LCPD frames how the professional development is designed.

Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework is based on the intersection of knowledge of technology, pedagogy, and content, and on the premise that in order for teachers to effectively use technology in their teaching they must possess and be able to apply these aspects of knowledge in an integrated manner (Mishra & Koehler, 2006; Niess, 2005). In the case of this study, the professional development focused on teachers' use of an internet-based formative assessment tool and then on implementing instructional activities based on the data. Technological Pedagogical Knowledge (TPK), in this study, involves using technology to collect and analyze formative assessment data, and also to support teaching and learning in the mathematics classroom. This use of technology to collect and analyze formative assessment data is an extension of typical views of TPACK, which focuses on how teachers integrate technology, pedagogy, and content into their teaching.

Technological Content Knowledge (TCK) relates to using technology to both assess mathematics concepts and teach math concepts. The internet-based formative assessment tool, *AMC Anywhere* (Didax, 2012), has nine different assessments, each with multiple tasks. Teachers are expected to apply knowledge about how to collect, analyze, and make use of data related to the specific mathematics concepts, and also leverage effective instructional activities that can be used to support students' learning of specific content.

TPACK in this study focuses on applying knowledge of technology, pedagogy, and content in the classroom to support the teaching and learning of mathematics (Niess, 2005; Polly & Orrill, 2012; Polly & Orrill, 2016). This relies on selecting and using appropriate instructional tasks and activities based on the data collected during the formative assessment process.

In addition to the three aspects of TPACK knowledge and their intersections, mathematics educational researchers have argued that teachers need specialized knowledge in order to effectively teach mathematics (Ball, Thames, & Phelps, 2008). This includes aspects such as knowledge of students and the curriculum, and how students best learn specific mathematics concepts. In this study, we recognize that these specialized aspects of knowledge are important. These aspects of knowledge have been included in the design of the professional development and are more broadly considered under knowledge related to pedagogy since they will be evident during teachers' instruction, where aspects related to pedagogical knowledge are most readily seen.

Learner-Centered Professional Development (LCPD)

The APLUS professional development project, which this chapter describes, was framed around the research-based framework of learner-centered professional development (LCPD). The construct of LCPD emerged a few decades ago when educational leaders applied the American Psychological Association's *Learner-centered Principles* (APA Work Group of the Board of Educational Affairs, 1997) to the idea of teacher learning (Hawley & Valli, 2000). Table 1 provides an overview of LCPD as it aligns to this project. In the LCPD approach, the activities for teacher learning and the content are based on the needs of the learners, who are typically classroom teachers. Polly and Hannafin (2010) synthesized the LCPD construct and research on teacher learning and identified that LCPD programs should have the following characteristics: focus on concepts in which students typically underperform (Hawley & Valli, 2000); provide teachers with ownership or choice in some workshop activities (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010); actively engage teachers in activities that develop both their knowledge of content and pedagogy (Garet, Porter, Desimone, Briman, & Yoon, 2001); allow teachers to collaborate with each other (Glazer, Hannafin, Polly, & Rich, 2009); support teachers with ongoing, comprehensive opportunities for learning (Heck, Banilower, Weiss, & Rosenberg, 2008); and allow teachers the opportunity to use new pedagogies in their classrooms and reflect on their effectiveness (Borko, 2004; Heck et al., 2008).

LCPD approaches have been effective in previous projects. The seminal Cognitively Guided Instruction (CGI) project aligned to LCPD, in that teachers actively explored mathematical tasks, examined student work, and analyzed subsequent tasks and activities based on student performance (Fennema et al., 1996). CGI led to teachers' implementing more tasks that were appropriate to their students' mathematical ability, which in turn increased students' achievement on problem-solving assessments (Carpenter, Fennema, & Franke, 1996).

In a large-scale LCPD project focused on teaching the standards-based mathematics curriculum *Investigations in Number, Data, and Space* (TERC, 2008), researchers found gains in teachers' use of learner-centered pedagogies, shifts towards learner-centered beliefs about how children learn mathematics, gains in teachers' mathematical knowledge for teaching (Polly, Wang, McGee, Lambert, Martin, & Pugalee, 2014; Wang, Polly, Lehew, Pugalee, Lambert, & Martin, 2013). Further, there were documented gains in student performance on curriculum-based assessments (Wang et al., 2013; Polly, McGee, Wang, Martin, Lambert, & Pugalee, 2015). Further, in an LCPD program focused on supporting teachers' use of technology-rich mathematical tasks, teachers used technology more frequently in their mathematics classrooms; also, after extensive support in co-planning lessons and receiving feedback, they integrated a greater number of higher-level technology-rich tasks (Polly & Hannafin, 2011).

While LCPD holds promise to impact teachers' instructional practices, their beliefs, and student achievement, teachers require extensive time in these programs or extensive classroom support to effectively integrate the emphasized pedagogies into their teaching (Heck et al., 2008; Polly, 2012; Polly & Hannafin, 2011). An evaluation of the National Science Foundation Local Systemic Change professional development programs found that changes in instructional practice were not clearly evident until teachers had participated in 30 hours of professional development, and gains in student learning outcomes were

Table 1. Alignment of the APLUS project to LCPD

LCPD Component	Description of APLUS Professional Development
Focused on concepts where students underperform	The APLUS project focused on primary grades' understanding of number sense.
Provide teachers with ownership of aspects of their learning	The APLUS project allowed teachers to choose which instructional activities to explore during periods of the workshops. In their classrooms, teachers chose which levels to use for each assessment as well as the associated instructional activities to use.
Actively engage teachers in developing knowledge of content and pedagogy	Teachers spent time in workshops exploring mathematical tasks, analyzing activities, and discussing how to implement the activities to deepen their knowledge of content and pedagogy.
Allow teachers to collaborate with each other	Teachers collaborated with others for all workshop activities. Teachers were encouraged to collaborate with their colleagues on their grade level during the school year.
Support ongoing, sustained professional development	Teachers participated in 80 hours of professional development during the year, including a summer institute and online activities that focused on classroom-embedded activities.
Allow teachers to use new pedagogies and reflect on their experience	Teachers used the *AMC Anywhere* tool in their classroom to assess their students and differentiate instruction, and reflected on their experience during the online modules.

not common until teachers had participated in at least 60 hours of professional development (Banilower, Boyd, Pasley, & Weiss, 2006).

DESCRIPTION OF FORMATIVE ASSESSMENT TOOL

The internet-based formative assessment tool, *AMC Anywhere* (Didax, 2012), was the focus of this project. The tool includes nine different assessments that progress from counting concrete objects to solving two-digit addition and subtraction tasks. The assessments focus on number sense concepts emphasized in kindergarten through Grade 2 of the Common Core State Standards in Mathematics (Common Core State Standards Initiative [CCSSI], 2011). The tool, developed by Kathy Richardson, follows the critical learning phases that she developed from her work with primary-grades students (Richardson, 2012). The assessments are designed to be conducted with a teacher and one student at a time. They vary in length and can take from 3 to 10 minutes to assess each student.

Figure 1 provides a picture of the Hiding Assessment, where students are given a number of counters while the teacher (or the one assessing) hides some counters. Students are told how many total there are and have to identify the number that is hiding. As seen in the picture, the tool records both the student's answer and the strategy that is used. Both of these data sources are used in a generative manner to determine what the next task will be, and to determine the student's rating on the assessment. The ratings are either: I: Needs Instruction, P: Needs to Practice, or A: Ready to Apply. These are used when teachers design subsequent instructional activities.

After students are assessed, their data are stored in the *AMC Anywhere* system. Teachers are able to run reports on individual students or a class of students. Figure 2 shows a Classroom Instruction Report, which summarizes students' performance and current working level for that specific assessment. The

Figure 1. Screen picture of the hiding assessment
(Reprinted with permission from Martin & Polly, 2015)

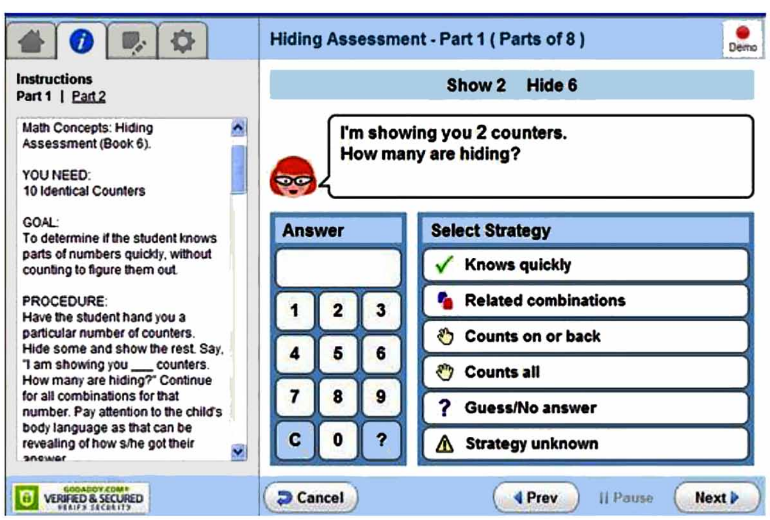
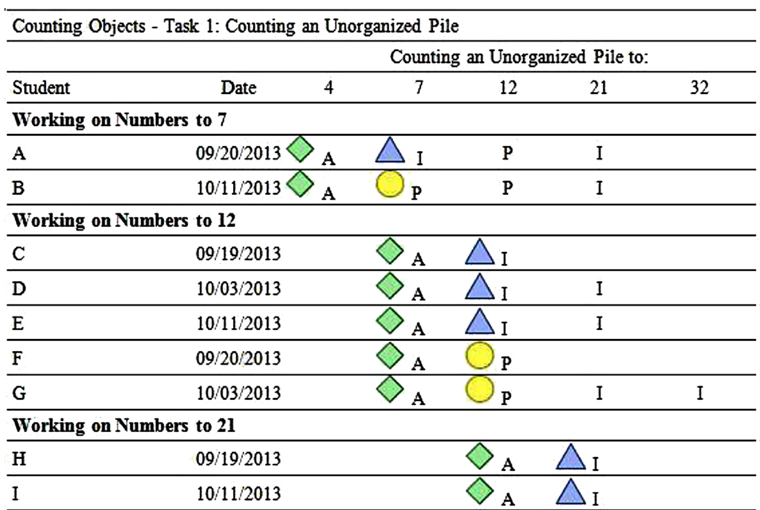


figure shows a report for the Counting Assessment, where students are given an unorganized or scattered pile of counters and have to count each one. The ratings, as stated before, are based on student performance on the assessment, and are used by teachers to determine further instructional activities. As part of the APLUS professional development project, teachers were given access to the *AMC Anywhere* internet-based tool as well as a set of related instructional materials that align to the specific assessments.

The *AMC Anywhere* system is designed to accompany the Developing Number Concepts curricular resources (Richardson, 1998). Table 2 shows a sample chart aligning students' levels from *AMC Anywhere* to instructional activities in Developing Number Concepts. Teachers would examine the report from Figure 2 and then use the resources to select appropriate instructional activities, including the activities and the range of numbers that specific students would work with.

Figure 2. Screen picture of the classroom instruction report
(Reprinted with permission from Martin & Polly, 2015)



Counting Objects - Task 1: Counting an Unorganized Pile						
			Counting an Unorganized Pile to:			
Student	Date	4	7	12	21	32
Working on Numbers to 7						
A	09/20/2013	A	I	P	I	
B	10/11/2013	A	P	P	I	
Working on Numbers to 12						
C	09/19/2013		A	I		
D	10/03/2013		A	I	I	
E	10/11/2013		A	I	I	
F	09/20/2013		A	P		
G	10/03/2013		A	P	I	I
Working on Numbers to 21						
H	09/19/2013			A	I	
I	10/11/2013			A	I	

Table 2. Chart aligning the Hiding Assessment to instructional activities

Independent Activities for Needs Instruction (I)		To 6	To 10
2:2-14	Number Arrangements: Using Cubes	X	X
2:2-15	Number Arrangements: Using Color Tiles	X	X
2:2-16	Number Arrangements: Using Toothpicks	X	X
2:2-17	Number Arrangements: Using Collections	X	X
2:2-18	Counting Boards: Making Up Number-Combinations Stories	X	X
2:2-20	Number Shapes: Using Number Cubes	X	X
2:2-21	Number Shapes: Using Spinners	X	X

(From Richardson, 2012).

DESCRIPTION OF PROFESSIONAL DEVELOPMENT PROJECT

The APLUS project provided approximately 80 hours of professional development to teachers in six districts across North Carolina. The project supported teachers' use of formative assessment processes with a focus on teachers' use of the internet-based tool, *AMC Anywhere*. Funded by the North Carolina Department of Public Instruction, the project included three cohorts with each cohort participating from July through the end of the following school year (approximately 11 months). Each year the professional development included a combination of 36 hours of face-to-face workshops and approximately 44 hours of classroom-based activities that were delivered and facilitated through an asynchronous online format.

The face-to-face workshops were facilitated by experts who were trained to use the *AMC Anywhere* formative assessment system. In Year One, Math Perspectives professional facilitators came and facilitated the workshops. In Years Two and Three, local facilitators who had extensive experience with *AMC Anywhere* led the workshops. These local facilitators were all chosen by project staff based on their extensive use of *AMC Anywhere* in the classroom, as well as past experience facilitating mathematics professional development workshops.

The goal of the APLUS project was for teacher-participants to:

- Develop an overview of all nine assessments and the critical learning phases of number sense,
- Explore three of the assessments in depth,
- Explore various instructional activities that aligned to the three assessments that were examined in depth,
- Practice the assessments with teachers and also primary grades children, and
- Analyze data that they collected and collaboratively decide subsequent instructional activities.

In Years 2 and 3, modifications were made to the workshops as feedback from teachers and district leaders indicated the workshops should more closely integrate *AMC Anywhere* and the related activities with district curriculum *Investigations in Number, Data, and Space* (TERC, 2008). Further, there was a request to better address how the assessments and activities align to the Common Core State Standards for Mathematics (CCSSI, 2011). Local facilitators in Years 2 and 3 did this in each of the workshops while teacher-participants explored assessments and instructional activities.

During the face-to-face workshops, teachers analyzed in depth the four assessments and the related instructional activities by watching videos of assessments with students, doing the assessments with one another, and assessing students who were in a local summer camp. Teacher-participants also spent time working on the instructional activities in the Developing Number Concepts resources, unpacking related Common Core Standards, and discussing the relationship between *AMC Anywhere*, the Standards, and their district curriculum resources.

The online professional development activities in the APLUS project took place during the school year in a series of three modules delivered in a learning management system (Polly et al., in press). The three modules focused on classroom-based activities related to using the *AMC Anywhere* assessment. Module 1, completed during September and October, supported teacher-participants as they set up their classrooms at the beginning of the year, specifically thinking about how they were going to differentiate instruction and implement small group mathematics activities. Module 1 also provided support as teacher-participants used *AMC Anywhere* to assess their entire class and then used that data to begin differentiating instruction. Module 2, completed during January and February, went deeper into data analysis and instructional planning as teacher-participants assessed their entire class again and made instructional plans for the entire class. Participants also spent time making an in-depth plan for monitoring student progress over a sustained amount of time for a small group of students who were not performing at grade-level expectations. Module 3, completed during April and May, provided support for teachers for a third round of *AMC Anywhere* data collection and analysis. Module 3 also introduced students to Number Talks (Parrish, 2014) and ways to support mathematics discussions in the classroom.

During the three years of the project, Module 1 remained the same. During the second year of the project, Module 2 was modified to provide further support of the instructional planning process with more prompts and structure about teachers' instructional plan. Module 3 also was modified to include more support for teachers' instructional planning after collecting *AMC Anywhere* data. Participating districts had the option to supplement the online professional development with face-to-face workshops if they wanted. One district provided one additional half-day face-to-face workshop during the year, and another district allowed teachers to meet together on a workday to collaboratively work on parts of the online modules related to data analysis.

METHODS

In this chapter we provide a holistic overview of the impacts of the APLUS professional development project. Our data analysis and findings are presented through the TPACK framework.

Specifically, this chapter examines the following research questions:

1. What was the influence of the professional development on teachers' TPACK?
2. What was the influence of the professional development on teachers' formative assessment practices?

Participants

As stated earlier, the APLUS professional development project was implemented in three one-year-long cohorts. Teacher-participants completed district-based professional development during the summer in six high-need school districts in North Carolina in the United States. Each district had been introduced to *AMC Anywhere*, but teacher-participants had never used the tool prior to beginning the workshops. Teaching experience ranged from one year of experience to 25 years of experience.

Each teacher-participant held an Elementary Education teacher license in North Carolina, which provides credentials to teach kindergarten through Grade 6. The project included kindergarten and Grade 1 teachers in Year One, Grade 1 and 2 teachers in Year Two, and Grade 2 and 3 teachers in Year Three. Year One included 296 teachers, Year Two included 185 teachers, and Year Three included 392 teachers. Years One and Three had more participants, due to the amount of funds allocated by the North Carolina Department of Public Instruction. The number of participants in each district was based on the size of the district and grant funding. Two large districts included 90-100 teachers per year, while the four other smaller districts included between 25-35 teachers per year. Project personnel worked with district leaders to recruit participants who taught in those specific grades and had administrative support to use the *AMC Anywhere* tool in their school the following year.

Data Sources and Analysis

Prior studies have been disseminated regarding this project (see Martin & Polly, 2015; Polly et al., 2014a; Polly et al., in press). In this chapter, we aim to synthesize the work across three years to highlight key findings that have emerged from our analysis of the data.

For the research questions, qualitative data from the workshop survey and the online activities were analyzed thematically (Patton, 2015). The workshop survey was developed in the first year of the project by project staff, and was revised after consultation with district leaders who were overseeing the APLUS professional development project in their districts. The survey questions focused on teachers' use of formative assessment practices prior to the project, their reactions to learning about the *AMC Anywhere* internet-based tool, and their plans for using the tool in their classroom. Participants completed the survey at the beginning and at the end of the summer professional development. Further, researchers analyzed teacher-participants' instructional plans to better understand how they use data to make instructional planning decisions. This was part of Research Question Two.

Data were coded using an open coding process and organized into themes. Once themes were generated, the data was then revisited to confirm alignment between themes and the original data. For question one, findings are described based on the aspects of the TPACK framework. For question two, findings are organized by the themes that were identified during data analysis. Trustworthiness was established through the iterative process of data analysis described above. The original data was checked twice during the process of coding data and organizing the data into themes.

FINDINGS

Previous research studies about the APLUS professional development project have found an increase in teachers' use of formative assessment practices (Polly et al., 2014a; Martin & Polly, 2015), gains in student learning outcomes (Polly et al., 2014a), and improvements in teachers' ability to make data-based instructional decisions (Polly et al., in press). Below we provide the findings in response to the two research questions.

Research Question One

Survey data were collected at the end of the summer workshops in order to respond to the first research question that considered the influence of the professional development on teachers' TPACK. The analyses indicated the following themes:

1. Increased knowledge about the formative assessment process,
2. Increased confidence using technology, and
3. Increased knowledge about selecting appropriate activities.

Increased Knowledge about the Formative Assessment Process

Participants reported on the survey that they had gained increased knowledge about what formative assessment is and what it looks like in the classroom. Teacher responses varied: some focused specifically on formative assessment in mathematics while others focused more generally on formative assessment processes.

Teacher-participants who wrote specifically about mathematics talked about the perceived benefit of formative assessment for their students. One kindergarten teacher wrote, "I feel that the use of *AMC Anywhere* will help me pay closer attention to my students' growth in mathematics. That in turn will make me more effective at reaching the different levels of my students."

A first grade teacher wrote, "By using *AMC Anywhere* and then using the data to plan instruction and differentiate will make my students more likely to succeed in mathematics." These responses and others like them relate to Pedagogical Content Knowledge (PCK) in that teachers' responses focused heavily on pedagogies related to formative assessment in general, and TPACK when they spoke about how the technology supported the process of formative assessment practices in mathematics.

The teachers who wrote more generally about formative assessment practices included comments such as this statement from a second grade teacher: "The workshops have taught me to collect data and information about my students more frequently than just at the end of units." Another second grade teacher wrote, "I can see how this process can be used in all subjects to collect data and then use that data to form my small groups to meet my students' needs." A kindergarten teacher also wrote generally about formative assessment: "I have learned that just by observing and watching students work I can gather information on what they do and do not know." These general statements aligned with Pedagogical Knowledge (PK). Teachers who made these types of comments did not focus on the *AMC Anywhere* tool or the mathematics content. Their comments were focused solely on the pedagogies associated with formative assessment.

Increased Knowledge about using Technology

On the surveys at the end of the workshop, nearly all teachers reported increased confidence in using technology. However, their responses about technology primarily focused heavily on their confidence and self-reported knowledge about using the *AMC Anywhere* tool to collect data on their students' mathematical understanding. One kindergarten teacher wrote, "The workshops taught me how to use the *AMC Anywhere* website to assess my students. It is very similar to M-Class and the technology that we use for reading assessment."

Twelve other comments focused on teachers learning how to use the technological tool for data collection and for formative assessment processes, such as generating reports and using the *AMC Anywhere* tool to group students. These ideas aligned with TPK, as teachers wrote about learning about the tool to support formative assessment practices in general rather than emphasizing for their mathematics classes. However, some comments aligned with TPACK in that they referenced the *AMC Anywhere* tool to support formative assessment pedagogies related to mathematics. One first-grade teacher wrote, "I learned how to use the *AMC Anywhere* program to find out what my students know in regards to number sense and place value. It gives me another source of data in addition to my daily observations."

A second-grade teacher wrote, "I learned how to use the program to assess students about their number sense and then how to use it to generate reports that have my small groups already determined for me." The only difference between the TPK and TPACK responses was the mention of mathematics content in their statements. All teachers who wrote comments about mathematics referenced number sense, which was the focus of the assessments. Still, all comments that mentioned learning about and gaining confidence in using technology focused heavily on mathematics-focused technology (TCK) and technology to complete the formative assessment processes (TPK).

Increased Knowledge Selecting Appropriate Instructional Activities

Analysis of the surveys completed at the end of the summer workshops indicated that teacher-participants developed knowledge related to selecting appropriate instructional activities that were based on the data collected through the *AMC Anywhere* tool. The *AMC Anywhere* tool provided detailed instructional reports (Figure 2) that grouped students according to their performance, and with the use of the instructional resources, teachers selected appropriate instructional activities based on the data. The workshop provided teachers opportunities to analyze and examine instructional activities that were explicitly aligned to the various *AMC Anywhere* assessments.

A kindergarten teacher wrote on her survey,

It was very powerful to have access to the classroom reports and then be able to see exactly which instructional activities each group of students should work with during math workshop as we develop number skills. Learning how to use the reports was helpful.

In some cases, teachers reported on the benefit of analyzing the instructional activities during the workshops. Teachers spent a lot of time comparing the mathematics concepts in the assessments to those in the activities to confirm their alignment. Another kindergarten teacher commented, "I feel that I learned a lot about how to choose instructional activities that were based on the *AMC Anywhere* data and how my students can count. The activities are directly aligned which is nice to have." In both responses above, and in others like them, teachers reported developing knowledge related to using the *AMC Anywhere* reports to select instructional activities focused on specific mathematics concepts (PCK).

Some teachers wrote broader responses focused on the process of using data to select instructional activities (PK). One second-grade teacher wrote, "The *AMC Anywhere* tool, like reading assessments, is just another example of how I can use data to select which types of activities my students should do in class." Another second-grade teacher commented, "I learned more about the process of selecting center activities more carefully based on the information about students." The responses in the theme about selecting appropriate instructional activities did not reference technology at all. Each of them focused on the pedagogies of selecting and implementing instructional activities (PK) and at times mentioned mathematics concepts (PCK).

Research Question Two

The second research question focused on the impact of the professional development on the teachers' formative assessment processes. The teacher-participants completed a series of instructional activities during the online modules that made evident their use of knowledge and skills related to formative assessment in mathematics. Similar to Research Question One, these responses were analyzed in light of the TPACK framework. The data analysis revealed four major themes as detailed in this section: 1) small groups to differentiate instruction, 2) assessing students' mathematics performance in multiple ways, and 3) making instructional decisions based on data.

Use of the AMC Anywhere Tool

Data across the three years of the project indicates that 100% of the teachers in the project used *AMC Anywhere* at least to assess their students' mathematics understanding. However, there was variance in the number of times the assessment tool was used. The project leadership strongly encouraged specific assessments three times during the year in order to examine students' growth. Kindergarten teachers were encouraged to give the Counting Objects assessment, in which students count an existing set of concrete objects, count out a pile to match a specific number, and then orally tell the teacher what one more and one less than a number is. Grade 1 and Grade 2 teachers were encouraged to give the Hiding Assessment, which required teachers to decompose numbers and determine missing addends using concrete objects in one part and use mental strategies in part two.

Teachers reported mixed reviews about the alignment between *AMC Anywhere* and their grade level standards. Kindergarten teachers reported only positive feedback, since counting is a critical area. One teacher wrote, "It is great to be able to look at students' counting progress over time and have access to the reports to help me plan specific activities for them to do during workshop." A second-grade teacher wrote, "Using Kathy Richardson and Investigations data, I have been able to keep a flexible, ever changing list of students who will receive math intervention time." However, first- and second-grade teachers reported a bit more confusion about how *AMC Anywhere* addresses their grade level standards. One first-grade teacher wrote, "I do not see the alignment to our standards compared to our curriculum and those assessments. It is hard to decide whether to focus on *AMC* assessments or other assessments more aligned to our standards."

The required time to use *AMC Anywhere* was another concern of teachers. In their reflections in the online modules, teachers reported that their use of the *AMC Anywhere* tool was time consuming and took at times 15 to 20 minutes to assess one of their students. One first-grade teacher wrote, "While I see the benefit in this tool, it is very time consuming. After the grant I don't see myself using this tool with the whole class. Maybe just with my struggling students to monitor growth."

Use of Small Groups to Teach Mathematics

In the first module completed during the fall of the school year, teachers were prompted to provide a description of their mathematics classrooms, and the typical activities that occurred. Every teacher reported using small groups in their mathematics classroom. In their responses, teacher-participants mentioned that they varied in how small groups were used. In some cases, teachers reported using small groups to provide more targeted instruction based on students' needs. However, in other cases, teachers reported using small groups to just play math games and have students each complete the same activities without differentiation.

One kindergarten teacher who shared about differentiating instruction in small groups wrote, "I use data from my observations and from *AMC Anywhere* to determine the size of numbers that my students are working with during workshops. This is really the biggest way that I meet students' needs." A second-grade teacher wrote,

My students all play the same math games often, but the size of the numbers is changed based on their level. The other day students were playing the cave game where they find the missing addends and working with parts of 5, parts of 8, or parts of 11.

The other subtheme that was related to small groups focused on teachers using small groups to organize students without any differentiation. One first-grade teacher wrote, "My students do three centers each day. Each center is a separate math game or activity and all of the students do the same game or activity." A kindergarten teacher wrote, "Our math curriculum includes activities for workshops that include 3 or 4 different games and center activities. Students do these over a few days and the activities are identical." These comments reflected teachers' use of small group instruction, but demonstrated that the teachers were doing very little or no differentiation of activities. These responses, just like those about differentiating through small groups, referenced the use of knowledge related to pedagogies specific to mathematics (PCK). However, the lack of differentiation indicated that teachers were implementing small groups, a goal of the professional development, but not differentiating instruction, which was also a goal of the APLUS project.

Assessing Students' Mathematics Performance in Multiple Ways

During Module 1, which was completed during the fall of the year-long professional development project, all teacher-participants reported that prior to the professional development, they had experience conducting assessments of students' mathematics performance. Within this theme, teachers shared examples of multiple mathematics assessments, including mid-year and end-of-year assessments, unit assessments, tests, and activity sheets or worksheets that were graded. Nearly all of the examples that were provided reflected summative or after-instruction measures. In terms of their activities prior to the professional development, no teachers shared how that data was used to modify or shape instruction.

Participants were also asked to describe their assessments during the first part of the school year after the summer workshops. These responses included post-instruction measures, such as unit assessments or activity sheets, as well as *AMC Anywhere* data. Below, this first-grade teacher comments about her increased attention to observing students as they work, "This year I still grade activity sheets, but I am collecting more data from watching my students during workshop and asking them to talk about their strategies." A second-grade teacher wrote, "The *AMC Anywhere* data helps add to our collection of data on our students. We have given a beginning-of-year test and assess [students based on] a number of worksheets. The *AMC Anywhere* data gives more evidence about my students' number sense skills." The responses above, and others like it, provide insight into how teachers are applying pedagogies related to assessment in mathematics (PCK). The reference to technology was minimal in these comments, as teachers sometimes mentioned the use of *AMC Anywhere* in their data, but only in name.

A few responses discussed the benefit of using technology to assess students. One second-grade teacher wrote, "I use activity sheets and the *AMC Anywhere* program. *AMC Anywhere* data is easier to collect than other assessments that I give because I don't have to grade or spend too much time analyzing it." A first-grade teacher also responded, "Prior to this year I did not assess students often, because of all of the time and paper involved. With *AMC Anywhere* I am able to quickly collect information on my students and get a report on their performance." There were 15 responses like this, which spoke explicitly about how technology supported assessment-related pedagogies in mathematics (TPACK). The benefits of technology focused on reducing the amount of paperwork, the time required to analyze and organize data, and the speed at which teachers can assess students.

Further, eight teachers reported using general pedagogies without any specific relationship to mathematics. A first-grade teacher wrote, "I am spending more time listening to my students this year to better understand them." Additionally, one second-grade teacher wrote, "This year I find it so beneficial to observe my students and ask them questions as they work." These comments reflected general use of pedagogical knowledge (PK). Data related to this theme aligned closely to the goals of the professional development. In each of teachers' responses, they reported using multiple measures to assess students' performance, which was a goal of the professional development. Further, all teachers reported using the *AMC Anywhere* tool as one of the data sources in their mathematics classrooms, but reported also using unit tests, observations, and activity sheets as other forms of data that they frequently analyzed.

Making Instructional Decisions Based on Data

Teacher-participants' responses to Module 2 focused on how teacher-participants were using data to make instructional decisions to meet their students' needs. All teachers who completed Module 2, in all years of the project, reported that they had assessed their students and were using that data in some manner to influence their instructional decisions.

In the instructional plans completed in Year One, teachers filled out a template in a Word document. Teachers all referenced the *AMC Anywhere* data and specific instructional activities, and provided a description of how the instructional activities positively influenced student achievement. The template, however, was limited in supporting teachers' rationale and writing about how they used the data to make instructional decisions; most responses were a list of data and instructional activities with little analysis. In both Years Two and Three, the instructional plan was modified to include only a series of prompts that asked teachers to share a summary of their data, the instructional activities that they planned on using, their rationale for these activities, and information about the impact of these activities on students' learning after teachers implemented them.

A more detailed analysis of instructional plans from Year Two of the project has already taken place (Polly et al., in press). That analysis indicated that, while all teachers reported using the *AMC Anywhere* tool and making instructional decisions, the extent to which they used the data to choose activities and differentiate their teaching varied greatly. Some teachers used the *AMC Anywhere* data and clearly communicated how they used the data to select specific instructional activities in light of various Common Core Mathematics Standards (Polly et al., in press). One instructional plan from a first-grade teacher included,

From the Hiding Assessment I found that some of my students did not know the parts of 5. As a result in workshop they are working on number pictures of 5 to work on their fluency related to adding up to 5 and subtracting from 5.

Some instructional plans, however, lacked specific details about what data teachers used, what specific instructional activities they were going to use, and what mathematics concepts or standards were aligned. The detailed analysis of instructional plans from Year Two of the project (Polly et al., in press) found that only 67.4% of the instructional plans included specific references to *AMC Anywhere* assessments or data, and that only 43.5% included a rationale about how data was used to determine instructional activities.

These findings indicated that the teachers' use of knowledge related to formative assessment pedagogies (PCK) varied greatly. In some cases, the teachers demonstrated in their instructional plans knowledge of the formative assessment process in terms of analyzing data, then selecting instructional activities based on the data. However, in some instructional plans, teachers did not clearly communicate either how they were using data to determine instructional activities or what instructional activities they were going to implement. The analysis of Year Two data found that there were statistically significant differences between school districts in the APLUS project (Polly et al., in press). Specifically, districts that provided some additional face-to-face workshops and had teachers collaborate in person on some of the modules demonstrated a higher percentage of instructional plans that explicitly connected the data to instructional activities.

SOLUTIONS AND RECOMMENDATIONS

This study examined teachers' development of knowledge related to formative assessment practices in mathematics using data from teacher surveys, online activities, and instructional plans that teachers completed as part of online professional development during the school year. The data analysis, in light of the TPACK framework, provided findings that warrant further discussion. These are: 1) the variance of formative assessment pedagogies for mathematics (PCK), 2) the relationship of technology to the formative assessment process in mathematics (TPACK), and 3) the influence of TPACK professional development on mathematics teachers' practice.

Variance of Formative Assessment Pedagogies for Mathematics (PCK)

As seen in Research Question Two, teacher-participants demonstrated variance in their use of formative assessment pedagogies in the classroom after the summer workshops and while completing the online modules. In light of the PCK framework, not all enactments of pedagogy may be high quality. As seen in the first theme of question two, all teachers reported using small group instruction in their mathematics classroom, which aligned with the goals of the APLUS project. However, some teachers used small groups only to organize the use of mathematics activities (not aligned) instead of using small groups to differentiate and meet students' specific learning needs (aligned). Further, in the third theme of question two, teacher-participants reported very different ways of using data to select instructional activities (Polly et al., in press); in some cases the data was explicitly linked to specific instructional activities with a clear rationale (aligned), but in numerous cases those connections were not clear (not aligned).

Prior studies on TPACK and teaching mathematics have found that, although there may be evidence of pedagogical knowledge in lesson plans or classroom observations, not all enactments of pedagogy are high quality (Martin & Polly, 2015). As a result, it is important to not limit data analysis to whether or not data matches or fits with various aspects of the TPACK framework. The pedagogical aspects of TPACK tend to be on a continuum, rather than dependent on sound pedagogies that are present or absent in observations or other data sources. In this study, the pedagogy of small groups was enacted by all teachers, but small group instruction was not used to differentiate instruction by all teachers. Intuitively, researchers would argue that while elements of PCK are present in both cases, the example of using small groups to differentiate instruction is a more aligned example of PCK based on the goals of the professional development. These instances of teachers modifying pedagogies in a way that did not align to the desired enactments have frequently been cited in literature (Polly & Hannafin, 2011; Henningsen & Stein, 1997).

In future studies, data analysis needs to further explicate how examples of pedagogies within TPACK align to the goals of programs, such as the APLUS professional development project. Prior work without the TPACK framework identified whether or not teachers' enacted pedagogies aligned to the pedagogies emphasized during workshops as well as teachers' intended and espoused pedagogies (Polly & Hannafin, 2011). While the absence of a framework allowed for more qualitative elaboration about alignment, the TPACK framework and the idea of PCK provided a theoretical base which still has the potential for helping make sense of teachers' enactments of technology-related instruction.

Relationship of Technology to the Formative Assessment Process for Mathematics (TPACK)

Niess and colleagues (Niess et al., 2009) described levels of Mathematics TPACK based on the extent of technology integration in mathematics classrooms. In the case of this study, technology was used as a tool to support formative assessment pedagogies, which were not always visible during classroom observations. Teachers in the APLUS project were supported in using technology, specifically the internet-based *AMC Anywhere* program, to assess their students' mathematical understanding and to analyze reports to help make subsequent instructional decisions. Based on Niess et al.'s model, Mathematics TPACK can be observed and enacted in classrooms. In the case of this study, we viewed Mathematics TPACK more broadly, as it was in both classroom work with the assessment of students, and the out of classroom work done by teachers to analyze data and plan instruction.

The argument could be made that TPACK should be constrained to include only instances of technology integration in classrooms during instructional time (Doering, Veletsianos, Scharber, & Miller, 2009). However, other frameworks of knowledge have posited that examinations of teachers' knowledge related to teaching should include teaching, planning, assessing, and other aspects of their work (Polly et al., in press; Thames & Ball, 2008). In that spirit, we hold also that TPACK encompasses knowledge seen outside of classrooms, including the use of technological tools to analyze data and make instructional decisions.

TPACK authors have contended that TPACK is most salient and apparent when applied in classroom practice or related settings (Mishra & Koehler, 2006; Niess et al., 2009). This study provided a twist on that idea in that TPACK most likely included a combination of evidence from outside and inside the classroom. More specifically, teachers used the *AMC Anywhere* assessments (TK), generated and analyzed a report about students' number sense (TCK), and then—based on a report—planned and carried out subsequent instructional steps (TPACK). In some cases, as stated in the section immediately before this section, TPACK was distorted as teachers did not implement pedagogies that aligned to the goals of professional development. In those cases, there was evidence supporting teachers' TCK, but not PK, PCK, or TPACK.

Researchers continue to question the use of the TPACK framework in research, especially in terms of the data sources and methods employed in studies (Brantley-Dias & Ertmer, 2013). Future research on projects such as APLUS should continue seeking ways to gather a preponderance of evidence about teachers' enactment of TPACK, both in and out of the time that they are teaching. Due to the number of teachers in the study, classroom observations and interviews was not a viable option. Subsequent studies, though, should more closely examine a small number of participants through interviews, observations, and analysis of student work. This idea would give a clearer example of TPACK related to formative assessment with multiple data sources.

Influence of Learner-Centered TPACK Professional Development on Teachers' Practice

The APLUS professional development project included simultaneous experiences deepening knowledge about the formative assessment process, the internet-based *AMC Anywhere* program, students' development of number sense skills, and instructional activities that aligned to both the Common Core State Standards and the students' mathematics levels. The professional development based on the learner-centered principles allowed teachers the freedom to participate in activities that deepened knowledge of technology, pedagogy, and content through the lens of improving students' mathematical understanding (Martin & Polly, 2015). Prior studies from this project have found gains in students' learning (Polly et al., 2014a) as well as high enactment of emphasized pedagogies (Martin et al., 2016). Future studies are needed to examine teachers' use of formative assessment pedagogies following their participation in the project.

The findings from this study indicate that teachers successfully used the *AMC Anywhere* tool and generated reports to help them with subsequent instructional decisions. The variance among participants was evident in their rationales and alignment between data and their instructional decisions (Polly et al., in press). To that end, for some teachers the summer workshop model with follow-up online asynchronous activities did not provide adequate support to help them develop and enact the goals of the professional development. The professional development research is flooded with studies about extensive and worthwhile follow-up experiences as well as building-level or classroom-level support to help teachers put into practice what they have learned (Polly & Hannafin, 2011; Fishman, Marx, Best, & Tal, 2003; Hawley & Valli, 2000). It is unclear if these types of supports would have led to greater implementation or if other factors interfered (Martin et al., 2016; Polly et al., in press). Regardless, there is a need to continue examining how best to provide professional development to teachers so that implementation of the emphasized pedagogies is more likely.

FUTURE RESEARCH DIRECTIONS

The study described here is part of a line of research documenting that the APLUS professional development project supported teachers' use of formative assessment practices, but barriers still exist. Among these, the amount of time needed for teachers to use the *AMC Anywhere* tool is a theme that emerged here as well as in past studies (Martin et al., 2016; Ringer, 2013). Further, some teachers reported uncertainty and confusion with how *AMC Anywhere* and the focus of the assessments aligned to their grade-level Common Core standards, and how *AMC Anywhere* could be used in conjunction with their curriculum.

Future research endeavors around formative assessment should explore ways to facilitate teachers' understanding of the alignment between formative assessment tools, their Standards, and their curricular resources. In order for teachers to adopt new pedagogies, they need to have buy-in that the pedagogies will benefit their students' learning and their teaching. The construct of teachers' beliefs was not examined in this line of research, but should also be considered in future work. Surely, teachers' beliefs about formative assessment influence their use of related pedagogies, including the internet-based tool described in this chapter.

Further, there is a need to further elaborate on the specific processes and thoughts involved with teachers' formative assessment processes. Research is needed to further examine teachers' comprehensive process of collecting data, analyzing data, making instructional decisions, and continuously revisiting their data to understand their students' mathematical understanding. This line of research must also be carried out to look at specific actions and practices that influence students' growth on both proximal assessments, like *AMC Anywhere*, and more distal assessments, such as standards-based or curriculum-based measures.

CONCLUSION

In the digital age, it is critical to adequately prepare teachers for effective technology use to enhance teaching and learning processes. In this chapter, we examined primary-grade teachers' use of an internet-based formative assessment tool, *AMC Anywhere*, after participating in learner-centered professional development. Our findings indicated that the 80-hour professional development project effectively encouraged teachers to use the tool, implement formative assessment practices, and document their use of data to design subsequent mathematics instruction.

This chapter continues a line of research on previously published findings (Martin et al., 2016; Polly et al., 2014a; Polly et al., in press) that shares how this project has positively influenced teachers' use of the formative assessment tool, students' growth in their understanding of number sense, and teachers' use of data to make instructional decisions. In this chapter, the data analysis identified instances of TPACK in teachers' use of the internet-based formative assessment tool, *AMC Anywhere*. Specifically, the TPACK teachers demonstrated was more highly developed, as they used technology to formatively assess their students and make instructional data-based decisions. In terms of Research Question One, the data from surveys indicated that teachers reported the development of various aspects of TPACK, including the use of general formative assessment practices (PK), mathematics formative assessment practices (PCK), and the use of technology to support formative assessment (TPK) with a focus in mathematics (TPACK). The data regarding Research Question Two indicated that the professional development led to increased use of the *AMC Anywhere* tool, the use of small groups to teach mathematics, and assessment of students' mathematical understanding in multiple ways.

Based on this line of research and the findings presented here, there is a growing body of evidence indicating that learner-centered approaches to professional development that focus on developing teachers' TPACK have potential to support teachers' development of new knowledge and skills that, in turn, are likely to positively influence their teaching and their students' learning. Further, the professional development model included a combination of both face-to-face workshops in the summer and online learning experiences during the school year, which provided teachers with flexibility and a focus on classroom-embedded learning opportunities. Online and hybrid models of professional development should be explored more closely, with a focus on building these experiences on a set of research-based design principles.

Lastly, the variance demonstrated among teachers indicates that the model of professional development may have been enough to support teachers' initial use of formative assessment practices, but there is still a need for more extensive, ongoing support in teachers' school buildings and possibly their classrooms. The role of in-school mathematics facilitators or coaches must continue to be explored in order to provide school-based support to teachers attempting to enact these new pedagogies in their classrooms (Polly, Algozzine, Martin, & Mraz, 2015).

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KEY TERMS AND DEFINITIONS

AMC Anywhere: An internet-based program that assesses elementary school students' understanding of number sense concepts.

Elementary Grades: Kindergarten (age 5) through Grade 5 (ages 10-11).

Formative Assessment: The process of collecting data on students' understanding, analyzing data, and making instructional decisions based on the data.

Learner-Centered Professional Development: A research-based construct on how to design effective opportunities for teacher professional development.

Number Sense: The skills and knowledge related to numbers in the elementary school grades; includes counting, place value, addition, and subtraction.

Primary Grades: Kindergarten (age 5) through Grade 2 (ages 7-8).

Professional Development: The experiences that provide practicing teachers with opportunities to advance their knowledge and skills.

Technological Pedagogical Content Knowledge (TPACK): A construct related to using knowledge of technology, pedagogy, and content in order to effectively teach with technology.