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# Elementary Education Candidates' Integration of Technology in Science Units

Drew Polly and Ian Binns
*University of North Carolina at Charlotte*

This study used the framework of technological pedagogical and content knowledge (TPACK) to examine how elementary education preservice teachers integrated technology in science units that they designed after completing courses on science education and technology integration. The findings indicate that technologies included at the end of lessons were associated with higher order thinking, while those included at the beginning or middle of lessons were focused more on lower order thinking and presenting content. Further, frequently used technology-rich activities such as viewing videos and PowerPoint presentations were associated with lower order thinking, while activities such as completing an interactive whiteboard activity or having students make presentations or videos included more opportunities to develop higher order thinking. Implications from this research suggest that science educators and teacher educators should focus more on technologies that support higher -order thinking and support course work with special attention to technology in the context of designing engaging science instruction.

## Overview

### Role of Technology in Elementary Schools

Technologies continue to show promise to enhance teaching and learning in the elementary school grades (New Media Consortium, 2017; U.S. Department of Education, 2016). When coupled with higher level thinking skills, technology has been found as a tool that positively impacts student achievement (Polly, 2008; Wenglinsky, 2000). Examples of activities that are technology rich and include higher level thinking skills include using technology to create products or artifacts of knowledge such as multimedia presentations or artifacts, using technology to locate and synthesize information, and using technological tools to explore and make sense of mathematics and science problems by generating representations or simulations (International Society for Technology in Education, 2016).

In this paper we define technologies as digital tools that include hardware and devices (e.g., computers, document cameras, and iPads), software and tools (e.g., PowerPoint and iPad applications), as well as infrastructure needed for technology, specifically the use of the internet.

In recent years in elementary schools, the addition of interactive whiteboards and projectors and one-to-one environments with either laptops or iPads has increased teachers' and students' access to tools to support teaching and learning processes (New Media Consortium, 2017). Research about how technology is used by teachers, however, indicates a predominance of teacher-centric pedagogies (Polly, 2015).

When considering how to best prepare teacher candidates (that is, preservice teachers) to be effective at designing and integrating technology in meaningful ways, there is a need to provide ample support with content-specific examples of technology integration (Tondeur, van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012). In this paper we report our examination of how elementary education preservice teachers intended to use technology in science units that they designed.

## Role of Technology in Elementary School Science

In science, technology continues to show promise as a tool to support the teaching and learning of concepts. Technology and science activities that promote problem solving and critical thinking lead to deeper learning of science concepts (Scalise et al., 2011; Trowbridge, Bybee, & Powell, 2008). Novak and Krajcik (2004) posited that technology was most beneficial when coupled with inquiry-based activities: "Utilizing technology tools in inquiry-based science classrooms allows students to work as scientists" (p. 76).

While technology infused into science classrooms with critical thinking and inquiry have potential, research from in-service teachers notes various barriers and factors related to technology integration. In a study of middle school and high school teachers, researchers found that teachers were able to use technology in inquiry-based experiences, but contextual factors and teachers' technology skills proved significantly to help or impede the use of technology (Gusey & Roehrig, 2009). A related study found that secondary science teachers reported gains in skills and knowledge related to technology integration by participating in an ongoing set of professional development experiences (Graham et al., 2009).

Research on preservice teachers has cited the need to develop skills and knowledge related to technology integration (Polly, 2010; Niess, 2005) and their self-efficacy related to teaching with technology (Kent & Giles, 2017), as well as to address the preconceived beliefs that future teachers have about teaching with technology (Cullen & Greene, 2011).

In her seminal work, Schrum (1999) posited that the three primary areas where technology integration knowledge is developed included (a) stand-alone educational technology courses, (b) pedagogy courses in various content areas such as science, mathematics and literacy, and (c) time in classrooms where practicing teachers model technology integration.

In a study of preservice teachers Bell, Maeng, and Binns (2013) found that situating learning of technology integration in specific science experiences during science pedagogy courses and in immersive clinical experiences in classrooms where teachers effectively used technology as a tool to teach science in an inquiry manner led to frequent enactments of technology while enacting inquiry-based pedagogies. For those teachers who struggled to integrate technology in inquiry, they still successfully integrated technology to display visuals through document cameras, PowerPoint presentations, and videos (Maeng, Mulvey, Smetana, & Bell, 2013).

Still, even when technology-rich learning experiences are modeled effectively and experienced by preservice teachers, preservice teachers have struggled to design and implement technology-rich experiences that consistently included inquiry or higher level thinking (Cullen & Greene, 2011; Polly, 2016). Specifically, preservice teachers tend to design and plan technology to be used only to present content in the form of electronic slideshow presentations, document cameras, and videos or provide practice of low-level basic skills (Polly, 2016; Maeng, et al., 2013).

## Technological, Pedagogical and Content Knowledge

This study is influenced by the framework of technological pedagogical content knowledge (Mishra & Koehler, 2006; Niess, 2005; now known as technological, pedagogical, and content knowledge, or TPACK). TPACK is often visualized as a three-ring Venn diagram (Figure 1) that represents knowledge related to technology, pedagogy, and content. Educational technologists posit that in order for teachers to effectively integrate technology, they must be able to apply knowledge from the center of the Venn diagram, which reflects a combination of knowledge related to technology, pedagogy, and content.

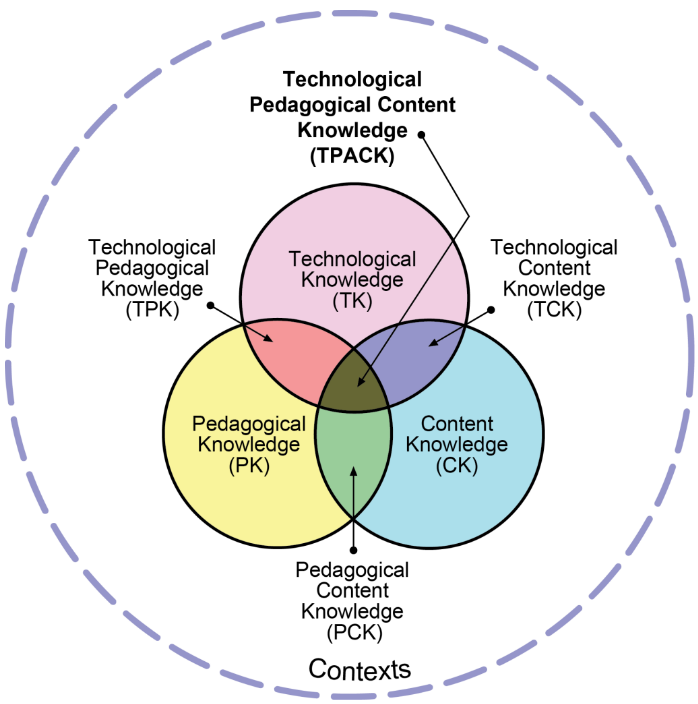


**Figure 1**. *TPACK model. (Reproduced by permission of the publisher, © 2012 by tpack.org)*

In the case of this study, the TPACK framework is used to examine the extent to which teachers designed an interdisciplinary unit that utilized technology and research-based pedagogies to teach science concepts effectively. The focus, therefore, was on instances of TPACK, that is, the center of the Venn diagram. TPACK refers to the knowledge related to teaching with technology and does not preference any particular pedagogical approaches (Harris, Mishra, & Koehler, 2010). TPACK can be used as a framework to examine evidence related to technology integration, including classroom observations (Polly, 2011), self-reported data (TPACK survey studies), and teachers' instructional plans (Polly, 2011, 2016).

***Developing TPACK Through the Design of Lessons and Units.*** Lesson design in teacher education programs is one way to develop preservice teachers' TPACK (Jang & Chen, 2010; Lee & Kim, 2014; Polly & Rock, 2016; Yoon, Ho, & Hedberg, 2006). Teacher educators used TPACK to design experiences in courses and classrooms, along with coaching to assist preservice teachers' design of technology-rich science lessons (Jang & Chen, 2010). Preservice teachers designed effective technology-rich science lessons and attributed the success to the candidates' school-based experiences and examples of technology-rich science instruction in both the science and the educational technology course (Jang & Chen, 2010).

Preservice and in-service teachers' enactment of TPACK during the process of designing instruction has been documented in prior studies. At the end of a course on instructional design and technology integration, preservice teachers successfully designed lessons that included instances of technology use with technologies specifically covered in the course (Polly, 2010). In a follow-up study (Polly, 2016) preservice teachers who had completed the planning and technology integration course two semesters earlier designed interdisciplinary units that included instances of technology. Most of these aligned to lower levels of Bloom's Revised Taxonomy (Anderson et al., 2000), however.

One plausible explanation was the lack of continued experiences in coursework and classrooms related to technology use and higher level thinking. That study examined units that included social studies and science. As researchers have cited, there is a need to more closely examine preservice teachers' TPACK and look for ways to develop it prior to the start of their teaching career (Lawless & Pellegrino, 2007; Maeng et al., 2013; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010).

The rationale for this study was to extend that work by taking a closer look at the inclusion of technology in science units. This study examined the broad research question: How did elementary education preservice teachers intend to integrate technology in science unit plans? While there was no specific, intensive treatment, this research aimed to discover more about how preservice teachers include technology into unit plans after completing experiences in courses and classrooms that have been cited as beneficial to developing preservice teachers' TPACK.

# Methods

## Participants and Context

Participants in this study were elementary education preservice teachers who were one semester from graduation at a large university in the southeastern United States. During the semester of the study, participants were taking five education courses on designing interdisciplinary units, assessing student learning, analysis of pedagogies and classroom management, modifying instruction for diverse learners, and modifying instruction for urban learners. Further, participants spent one full day in the elementary school classrooms where they would complete their internship in the final semester of their program. This study focuses on the work done in their course on designing interdisciplinary units.

This study examined seniors in an elementary education program who had completed a science pedagogy course in the preceding semester that included experiences using technology, seeing the instructor model technology, and observing technology use in science classrooms. The goals of these activities in the science education course were to show candidates how technology can support and not supplant other science resources and tools. Additionally, the instructors utilized technology to help students engage in learning about topics that they would not otherwise be able to do without the technology. For example, students used technology to examine how the continents have moved over time during an investigation on plate tectonics.

Two semesters before the study, participants completed a course focused on technology integration and instructional design (planning), which covered all concepts taught in elementary school classrooms. The focus in this course was participating in inquiry-based lessons as learners, in which technology was used by the instructor to support teaching and learning. One experience included the exploration of an internet-based simulation focused on the phases of the moon as it relates to the movement of the moon and earth. Further, candidates participated in lessons in which the instructor modeled the use of interactive whiteboards, document cameras, and technologies to create products such as screencasts, digital videos, or webpages.

## Data Sources and Data Analysis

This study used a two-stage mixed methods approach to analyzing the data (Patton, 2014). The data source in this study was the interdisciplinary science units that 63 candidates completed. Each interdisciplinary unit included five lesson plans and prompts that preservice teachers had to answer about their unit. The lesson plans were the primary data source for this study. A prompt about how students had integrated technology into their unit was used as a secondary data source.

Prior studies have found benefit in examining teachers' intent to integrate technology in their teaching through the analysis of lesson and unit plans (Hofer et al., 2009; Moallem, 1998; Moallem & Earle, 1998; Polly, 2014; Richardson, 2009). While some studies have found mixed results in how teachers' intended practices align to their enacted practices (Fishman, Marx, Best, & Tal, 2003; Polly & Hannafin, 2011), examining teachers' and teacher candidates' intended practices can still provide insight into their knowledge and skills related to various practices, including technology integration (Koehler, Mishra, & Yahya, 2007).

Based on the need to further examine teacher candidates' intended practices, we analyzed the lesson plans using inductive qualitative analysis (Coffey & Atkinson, 1996; Patton, 2014) citing every instance in which technology was integrated into the lesson. Examples of instances of technology include the use of PowerPoint electronic slides to provide visuals of content, the use of internet-connected computers to research science content, or the use of an interactive whiteboard to complete an activity.

Each instance of technology was entered into a spreadsheet in its own row along with details about the instance. These details were in predetermined categories that are described as follows:

- Type of technology. The type of technology that was in the unit plan.
- User of technology. Information was recorded about whether the teacher or students were using the technology.

- Lesson plan in the unit. The number of plan in the unit in which the technology was used. These were coded numerically from 1 to 5.
- Format of the lesson plan. The five-lesson unit had to include at least one direct instruction lesson and one indirect instruction lesson. Direct instruction plans are more traditional, with phases titled focus/review, teacher input, guided practice, and independent practice. Indirect instruction plans are more discovery-oriented with phases titled engage, explore, explain, and elaborate. These were coded numerically for analyses.
- Activity in the lesson plan. Each lesson plan format had four phases. Data were entered about what phase in the plan technology was integrated. These were coded from 1 to 4.
- Levels of technology use. This four-level scale was adapted from the LoTI framework (Moersch, 1995, 2010). Levels are based off the premise that higher levels of technology integration include students using technology to apply and work with higher order thinking skills that include synthesizing knowledge and creating new representations of knowledge and evaluating knowledge. Lower levels include teacher-focused uses of technology where the students are passive learners. Refer to Table 1 for descriptions of levels.

**Table 1**
Levels of Technology Use

| Level | Description | Example |
|---|---|---|
| 1 | Teacher only uses technology. Students do not use technology at all. | Teacher uses a document camera to display students' work on a science activity. |
| 2 | Student uses technology to watch a video, read a website, or acquire information. | Students watch a video about the phases of the moon. |
| 3 | Students use technology to apply knowledge by completing skills-based activities. | Students complete an iPad activity where they match up the phases of the moon with pictures |
| 4 | Students use technology to create a project or synthesize information. | Students create a VoiceThread in which they incorporate pictures and their own narration about the phases of the moon. |

Once the qualitative data were coded and entered into the spreadsheet, quantitative analyses were run on the various codes of data. Quantitative data analyses procedures were conducted using IBM Statistical Package for Social Sciences (SPSS) 21. Descriptive statistics and frequencies were calculated. Analyses also included chi-squared tests for independence in order to examine if there were statistically significant relationships between the various categorical data sources.

## Findings

This study examined the extent to which and how preservice integrated technology into interdisciplinary science units.

## How Technology Was Integrated in Interdisciplinary Science Units

There were 305 instances of technology integration in the 63 interdisciplinary science units, an average of 4.84 instances of technology per unit. The range of instances of technology varied from 1 instance (2 units) to as many as 11 instances (1 unit). Candidates completed their unit for the grade level in which they were completing their full-time student teaching internship. Table 2 details the types of technologies in the science units by grade level. Units written for kindergarten, Grade 1, and Grade 2 primarily included the use of interactive whiteboards, such as SMARTBoards, as well the internet for various activities.

Internet uses in these primary grades focused on showing a video of content or internet-based activities and games. In Grades 3-5, the Internet was the primary technology incorporated into the science units to show videos of content or conduct internet-based research about science concepts. Units in Grade 3 also used PowerPoint electronic slides to present content to students during lessons. All of the technologies included in the units were general technologies in order to support the teaching and learning of science content.

**Table 2**
Types of Technology by Grade in Science Units

| Technology | Kinder | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 | Total |
|---|---|---|---|---|---|---|---|
| Digital camera | 0 | 0 | 0 | 0 | 1 (100%) | 0 | 1 |
| Digital recorder | 1 (100%) | 0 | 0 | 0 | 0 | 0 | 1 |
| Document camera | 2 (11.1%) | 8 (44.4%) | 3 (16.7%) | 4 (22.2%) | 1 (5.6%) | 0 | 18 |
| Internet | 31 (19.0%) | 37 (22.7%) | 31 (19.0%) | 33 (20.2%) | 19 (11.7%) | 12 (7.4%) | 163 |
| iPad | 1 (12.5%) | 2 (25.0%) | 1 (12.5%) | 0 | 4 (50.0%) | 0 | 8 |
| PowerPoint slides | 2 (5.7%) | 6 (17.1%) | 8 (22.9%) | 12 (34.3%) | 4 (11.4%) | 4 (11.4%) | 35 |
| Skype video chat | 0 | 0 | 0 | 1 (100%) | 0 | 0 | 1 |
| Interactive whiteboard | 22 (30.6%) | 20 (27.8%) | 24 (33.3%) | 5 (6.9%) | 1 (1.4%) | 0 | 72 |
| Spreadsheet | 0 | 0 | 1 (100%) | 0 | 0 | 0 | 1 |
| Weather technology | 0 | 0 | 1 (100%) | 0 | 0 | 0 | 1 |
| Word processing software | 0 | 1 (33.3%) | 0 | 2 (66.7%) | 0 | 0 | 3 |
| Totals | 59 (1.93%) | 74 (24.3%) | 69 (22.6%) | 57 (18.7%) | 30 (9.8%) | 16 (5.2%) | 305 |

The internet was the top technology incorporated into units (162 instances), fairly evenly distributed across all six grades. Meanwhile, the second most-referenced technology was the interactive whiteboard (72 instances), with over 92% of those instances in kindergarten through second grade. The third most referenced technology was PowerPoint with 57.2% of those instances in Grades 2 and 3.

Table 3 refers to the times when candidates referenced technology in a lesson, specifically the beginning, middle, or end of a lesson. Candidates referenced technologies such as digital cameras, digital recorders, spreadsheets, weather technology, and word processing software at the end of a lesson when students were completing a project or an independent activity. There were also 21 uses of the internet as the final activity in the lesson, where students completed internet-based practice activities.

**Table 3**
Type of Technology Compared to When They Are Integrated Within a Lesson

| Technology | Beginning | Middle | End | Total |
|---|---|---|---|---|
| Digital camera | 0 | 0 | 1 (100%) | 1 |
| Digital recorder | 0 | 0 | 1 (100%) | 1 |
| Document camera | 1 (5.6%) | 13 (72.2%) | 4 (22.2%) | 18 |
| Internet | 48 (29.4%) | 94 (57.7%) | 21 (12.9%) | 163 |
| iPad | 0 | 4 (50%) | 4 (50%) | 8 |
| PowerPoint slides | 3 (8.6%) | 27 (74.3%) | 6 (17.1%) | 35 |
| Skype | 0 | 1 (100%) | 0 | 1 |
| Interactive whiteboard | 11 (15.3%) | 52 (72.2%) | 9 (12.5%) | 72 |
| Spreadsheet | 0 | 0 | 1 (100%) | 1 |
| Weather technology | 0 | 0 | 1 (100%) | 1 |
| Word processing software | 0 | 0 | 3 (100%) | 3 |
| Totals | 63 (20.7%) | 122 (40%) | 51 (16.7%) | 305 |

The interactive whiteboard, which was included in 72 instances, primarily occurred in the middle of the lesson, when teachers or students used it during a whole class activity or discussion. Last, the internet, which had 163 instances in the units, included 94 instances in the middle of the lesson and 48 instances at the start of the lesson. A majority of internet uses focused on playing videos about content either at the beginning of the lesson or after an opening exploration. Further, PowerPoint electronic slides were primarily included in the middle of the lesson to present content and to facilitate discussions.

Table 4 shows how the instances of technology integration occur within the five lessons in the unit, as well as whether they occur at the beginning, middle, and end of the lesson. Consistent with the total amounts, within each lesson most of the instances of technology occur during the middle of the lesson. For the first and third lessons of the units, candidates referenced more technology instances at the beginning compared to the end of the lessons. However, for the second, fourth, and fifth lessons, candidates referenced more technology instances at the end of the lesson compared to the beginning of the lesson. A chi-squared test of independence showed no significant differences across lessons or the time of the lesson in the unit which technology was integrated, $\chi(8) = 7.39$, $p = 0.50$.

**Table 4**
Time Within a Lesson Plan That Technology Was Integrated by the Plan Within the Units

| Plan | Begin | Middle | End | Total |
|---|---|---|---|---|
| 1 | 14 (23.3%) | 42 (70.0%) | 4 (6.7%) | 60 |
| 2 | 11 (16.7%) | 43 (65.2%) | 12 (18.2%) | 66 |
| 3 | 16 (24.6%) | 38 (58.5%) | 11 (16.9%) | 65 |
| 4 | 13 (20.6%) | 37 (58.7%) | 13 (20.6%) | 63 |
| 5 | 9 (17.6%) | 31 (60.8%) | 11 (21.6%) | 51 |
| Total | 63 (20.7%) | 191 (62.6%) | 51 (16.7%) | 305 |

## Relationships of Levels of Technology Use and Other Factors

Table 5 shows the lesson plans in the unit where technology was integrated by grade. A chi-squared test for independence indicated that there was no statistically significant relationship between which lesson plans in the unit integrated technology and grade level, $\chi(20) = 6.27$, $p = 0.99$.

**Table 5**
Lesson Plans in the Unit in Which Technology Was Integrated by Grade

| Grade | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| Kindergarten | 12 (20.3%) | 12 (20.3%) | 13 (22.0%) | 10 (16.9%) | 12 (20.3%) | 59 |
| Grade 1 | 16 (21.6%) | 19 (25.7%) | 12 (16.2%) | 14 (18.9%) | 13 (17.6%) | 74 |
| Grade 2 | 13 (18.8%) | 13 (18.8%) | 15 (21.7%) | 18 (26.1%) | 10 (14.5%) | 69 |
| Grade 3 | 10 (17.5%) | 11 (19.3%) | 15 (26.3%) | 11 (19.3%) | 10 (17.5%) | 57 |
| Grade 4 | 5 (16.7%) | 7 (23.3%) | 7 (23.3%) | 7 (23.3%) | 4 (13.3%) | 30 |
| Grade 5 | 4 (25.0%) | 4 (25.0%) | 3 (18.8%) | 3 (18.8%) | 2 (12.5%) | 16 |
| Total | 60 (19.7%) | 66 (21.6%) | 65 (21.3%) | 63 (20.7%) | 51 (16.7%) | 305 |

Table 6 shows the Level of technology use by grade. A chi-squared test for independence indicated that there was no statistically significant relationship between the level of technology use and the grade of the interdisciplinary science units, $\chi(15) = 13.48$, $p = 0.57$.

**Table 6**
Level of Technology Use by Technology in Science Units

| Technology | 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| Digital camera | 0 | 0 | 1 (100%) | 0 | 1 |
| Digital recorder | 0 | 0 | 0 | 1 (100%) | 1 |
| Document camera | 18 (100%) | 0 | 0 | 0 | 18 |
| Internet | 10 (6.1%) | 117 (71.8%) | 33 (20.2%) | 3 (1.8%) | 163 |
| iPad | 2 (25.0%) | 0 | 3 (37.5%) | 3 (37.5%) | 8 |
| PowerPoint slides | 27 (77.1%) | 0 | 3 (8.6%) | 5 (14.3%) | 35 |
| Skype | 0 | 1 (100%) | 0 | 0 | 1 |
| Interactive Whiteboard | 43 (59.7%) | 1 (1.4%) | 28 (38.9%) | 0 | 72 |
| Spreadsheet | 0 | 0 | 0 | 1 (100%) | 1 |
| Weather technology | 0 | 0 | 1 (100%) | 0 | 1 |
| Word processing software | 0 | 0 | 0 | 3 (100%) | 3 |
| Total | 100 (32.8%) | 119 (39.0%) | 70 (23.0%) | 16 (5.2%) | 305 |

Table 6 described the Levels of technology integration (LoTI) by technology. There were 219 instances (71.8%) aligned with Level 1 (100 instances) or Level 2 (119 instances). The internet was referenced 127 times in ways that aligned to Level 1 (10 instances) and Level 2 (117 instances). Those instances focused on the teacher using the internet or students viewing internet-based videos or texts.

The interactive whiteboard was associated with 28 instances (38.9%) of Level 3 uses, while the remaining instances were Level 1 (43 instances) or Level 2 (1 instance). Interactive whiteboard references primarily involved students viewing the board while the teacher modeled (Level 1) or using the whiteboard for an activity (Level 3).

Table 7 shows the level of technology use related to the place in a lesson plan in which technology was integrated. A chi-squared test for independence indicated a statistically significant relationship between the level of technology use and the location in a lesson, $\chi(6) = 111.15$, $p < 0.001$. Specifically, when candidates included technology early in a lesson it was nearly always as a tool for the teacher to provide content, such as a video or a

PowerPoint slideshow, while technology used later in lessons focused on students' use of technologies, such as interactive websites or iPads to complete an activity or project.

**Table 7**
Level of Technology Use and Time Technology Was Integrated Into Lessons

| Lesson Placement | 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| Beginning | 45 (71.4%) | 4 (6.3%) | 14 (22.2%) | 0 | 63 |
| Middle | 64 (33.5%) | 49 (25.7%) | 77 (40.3%) | 1 (0.5%) | 191 |
| End | 10 (19.6%) | 17 (33.3%) | 9 (17.6%) | 15 (29.4%) | 51 |
| Total | 119 (39.0%) | 70 (23.0%) | 100 (32.8%) | 16 (5.2%) | 305 |

# Discussion

## Placement of Technology in Plans Influenced Higher Order Thinking

Teacher candidates' plans to integrate technology at the end of lesson plans led to statistically significantly more instances of higher order thinking than did plans to integrate technology at the beginning or the middle of lesson plans. Specifically, plans to integrate technology at the end included opportunities for elementary school learners to create products using video technologies, PowerPoint slides, or complete internet-based or interactive whiteboard-based activities. Meanwhile, plans to use technology in the beginning of a lesson focused on teachers using technology with low levels, such as showing a video or using a PowerPoint presentation.

Consistent with prior studies with practicing teachers, teacher candidates in this study successfully designed and planned ways to integrate technology in order to support science instruction (Graham et al., 2009). However, in this study teacher candidates included technology that did not always support science inquiry, whereas teachers in Graham et al.'s study did. In this present study, many instances of technology use at the start of lessons and did not include inquiry.

Based on the findings in this study, it seems as if the barrier was not designing units with technology, but more so related to designing units in which technology supported science inquiry (Maeng et al., 2013). These candidates were seniors and only one semester removed from a science education course completely focused on teaching content through inquiry; yet, these candidates did not plan to use inquiry-based approaches with technology in their units. This finding provides evidence that teacher candidates' enactment of TPACK in their units is heavily influenced by their PCK, in this case, pedagogies related to inquiry methods to teach science.

There was a lack of statistical significance between levels of technology integration in the unit and variables such as grades, lessons within the unit, and part of the lessons. The most plausible interpretation of this from examining the data is an even distribution across either LoTI levels or the other variables examined.

Table 6 provides a closer look at how the technologies in the units aligned to LoTI. Some technologies were only associated with high LoTI (Levels 3 and 4), such as the use of digital cameras, digital recorders, spreadsheets, weather technology tools, and word processing software. There also was high LoTI related to 75% of references to iPads in the units. Since high LoTI align with high levels of Bloom's Revised Taxonomy (Moersch, 2011), these technologies all relate to students applying their knowledge of science concepts to create artifacts of their own learning (Level 4) or practice their knowledge and skills (Level 3). In the cases of these high LoTI instances, candidates demonstrated that they were able to design ways for students to use technology in meaningful ways.

### Further Consideration of TPACK

The ideas around the application of TPACK in classrooms and TPACK-in-action refer to teachers or preservice teachers integrating technology successfully in classrooms with learners (Herring, Koehler, & Mishra, 2016; Koh, Chai, & Tay, 2014). In this study, we did not collect data on preservice teachers' actual teaching with technology, but focused on the design of instruction, which is a foundational and critical step in the process of teaching with technology (Moallem, 1998; Moallem & Earle, 1998; Hofer et al., 2009; Richardson, 2009). Prior studies have looked at the design of instruction as preservice teachers' evidence of TPACK (Graham et al., 2009; Koehler et al., 2007; Polly, 2014) and found it possible to map instructional plans, lessons, and units to elements of TPACK.

In the present study, the frequent references to technology included in the units provided evidence of preservice teachers' technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological, pedagogical, and content knowledge (TPACK). A TCK example involved students watching a video about weather without any reference or evidence of teachers' pedagogies. The example is TCK because it includes specific technology, specific science content, but no specific pedagogies.

One example of TPK found in a unit involved having students use an interactive whiteboard for an activity in which they matched pictures of the water cycle with words that described them. During this activity in the unit, the teacher observed students, which is a general, nonscience-specific pedagogy. Since technology and a general pedagogy were used, it is an example of TPK.

An example of TPACK found in a unit involved having students use iPads and the ShowMe app to make a screencast where they drew a picture of erosion and orally explained in the screencast what was occurring. The teacher's role was to model how to use the app and provide feedback to students about the content in their screencast. This is identified as an instance of TPACK because it involves the intersection of the technology on the iPad, the feedback on content, and the teachers' pedagogies of modeling the activity and supporting students. Teacher candidates' units that did not teach science through inquiry, which is aligned with PCK, likely influenced how TPACK was enacted. Intuitively, if a teacher or teacher candidate is not going to teach science through inquiry, the inclusion of technology may not be enough to promote the shift from directly teaching science content to teaching through inquiry (Fishman et al., 2003).

### Implications for Future Work

Based on the findings, future studies should continue the in-depth analysis of preservice teachers' unit and lesson plans, but look for ways to expand on the corpus of data. Researchers could include require preservice teachers to teach one of their lessons and collect either video recordings of the lesson or student work samples. The analysis of student work samples may help to make the indelible link between teachers' enacted TPACK and student learning outcomes. Technology, when used in ways that support science inquiry, leads to deeper learning (Trowbridge et al., 2008). However, more work is needed to determine what elements of TPACK are at play in these instances of technology-enhanced science inquiry experiences.

Findings related to candidates' enactment of TPACK would be greatly enhanced by the analysis of evidence from candidates' teaching, including but not limited to notes from an observation from the classroom teacher or a university faculty member or a video that could be analyzed or examined by researchers or the candidate.

The use of video has been used in the past to examine how in-service teachers enacted elements of TPACK in mathematics while participating in professional development (Polly & Hannafin, 2011). Video gives a rich source of data that researchers can revisit multiple times based on the research questions or foci that are of interest.

This study also brings to light implications for teacher educators related to the fields of technology integration and science education. The TPACK framework is based on the premise that technology, content, and pedagogy are interrelated and essential for teachers to effectively integrate technology in their classrooms. Instructors of courses focused on educational technology, should provide content-specific experiences for candidates related to ways technology can support students during inquiry-based science lessons. The planning and design of instruction in courses focused on technology integration is also critical for candidates to develop TPACK related to science. During course activities candidates need ample opportunities to practice and get feedback on their design of lessons and units that include technology to support inquiry-based science experiences.

A recent study on technology integration models found that both teachers and teacher candidates value models and approaches to designing technology-enhanced instruction, but only if they are associated with and supported by learning theories (Kimmons & Hall, 2018). In both technology integration and science education courses it may be beneficial for course instructors to couple lesson and unit planning, technology integration with specific examples, and the rationale for teaching in this manner with a strong connection to learning theories.

Specifically, science education course instructors should include experiences in which candidates use technologies in the context of completing inquiry-based science activities or critical thinking activities, with specific time for candidates to discuss and reflect on how technology supports the teaching of science through inquiry and how that compares to other traditional uses of technology, such as showing a video or presenting content with PowerPoint slides. It is also imperative that candidates are placed in classrooms that not only teach science from an inquiry perspective, but also use technology to support inquiry-based approaches to teaching.

## References

Agyei, D. D., & Voogt, J. M. (2011). Exploring the potential of the will, skill, tool model in Ghana: Predicting prospective and practicing teachers' use of technology. *Computers & Education, 56*, 91-100.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2000). *A taxonomy of learning, teaching, and assessing: A revision of the Bloom's Taxonomy of educational objectives*. New York, NY: Pearson.

Bell, R.L., Maeng, J.L., & Binns, I.C. (2013). Learning in context: Technology integration in a teacher preparation program informed by situated learning theory. *Journal of Research in Science Teaching*, *50*(3), 348-379.

Coffey, A., & Atkinson, P. (1996). *Making sense of qualitative data analysis: Complementary strategies*. Thousand Oaks, CA: Sage.

Cullen, T. A., & Greene, B. A. (2011). Preservice teachers' beliefs, attitudes, and motivation about technology integration. *Journal of Educational Computing Research*, *45*(1), 29-47.

Drent, M., & Meelissen, M. (2008). Which factors obstruct or stimulate teacher educators to use ICT innovatively? *Computers & Education, 51*, 187-199.

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teachers and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*(6), 643-658.

Graham, C. R., Burgoyne, N., Cantrell, P., Smith, L., St. Clair, L., & Harris, R. (2009). TPACK development in science teaching: Measuring the TPACK confidence of inservice science teachers. *TechTrends*, *53*(5), 70-79.

Gusey, S. S., & Roehrig, G. H. (2009). Teaching science with technology: Case studies of science teachers' development of technology, pedagogy, and content knowledge. *Contemporary Issues on Technology in Education*, *9*. Retrieved from: http://www.citejournal.org/volume-9/issue-1-09/science/teaching-science-with-technology-case-studies-of-science-teachersdevelopment-of-technology-pedagogy-and-content-knowledge/

Harris, J., Mishra, P., & Koheler, M. (2009). Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed. *Journal of Research on Technology in Education*, *41*(4), 393-416.

Herring, M. C., Koehler, M. J., & Mishra, P. (2016). *Handbook of technological pedagogical content knowledge (TPACK) for educators* (2nd ed.). New York, NY: Routledge.

Hofer, M., Harris, J., Blanchard, M., Grandgenett, N., Schmidt, D., van Olphen, M., & Young, C. (2009). Operationalizing TPACK for educators: The activity types approach to technology integration, Part 1. In C. Crawford, D. A. Willis, R. Carlsen, I. Gibson, K. McFerrin, J. Price, & R. Weber (Eds.), *Proceedings of the Society for Information Technology and Teacher Education International Conference 2009* (pp. 4099-4102). Chesapeake, VA: AACE.

International Society for Technology in Education. (2016). *ISTE Standards for Students*. Retrieved from https://www.iste.org/standards/for-students

Jang, S. J., & Chen, K. C. (2010). From PCK to TPACK: Developing a transformative model for preservice science teachers. *Journal of Science Education and Technology*, *19*, 553-564.

Kent, A. M., & Giles, R. M. (2017). Preservice teachers' technology self-efficacy. *SRATE Journal*, *26*(1), 9-20.

Kimmons, R., & Hall, C. (2018). How useful are our models? Pre-service and practicing teacher evaluations of technology integration models. *TechTrends,* **VOL #?** 29-36.

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy, and technology. *Computers & Education*, *49*, 740-762.

Koh, J.H.L., Chai, C.S., & Tay, L.Y. (2014). *TPACK-in-action: Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK). Computers & Education, 78,* 20-29.

Lawless, K.A., & Pellegrino, J.W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research*, *77*(4), 575-614.

Lee, C., & Kim, C. (2014). An implementation study of a TPACK-based instructional design model in a technology integration course. *Educational Technology Research and Development*, *62*, 437-460.

Maeng, J. L., Mulvey, B. K., Smetana, L. K., & Bell, R. L. (2013). Preservice teachers' TPACK: Using technology to support inquiry instruction. *Journal of Science Education and Technology*, *22*(6) 838-857.

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

Moersch, C. (1995). Levels of technology implementation (LoTI): A framework for measuring classroom technology use. *Learning and Leading with Technology*, *23*(3), 40-42.

Moallem, M. (1998). An expert teacher's model of thinking and teaching and instructional design models and principles: An ethnographic study. *Educational Technology Research and Development*, *46*(2), 37-64.

Moallem, M., & Earle, R. (1998). Instructional design models and teacher thinking research: Toward a new conceptual model for research and development. *Educational Technology*, *38*(2), 5-22.

Moersch, C. (2010). LoTI turns up the heat. *Learning and Leading with Technology*, *37*(5), 20-23.

New Media Consortium. (2014). Horizon Report: K-12 edition. Retrieved from http://www.nmc.org/publications/horizon-report-2013-k-12-edition

New Media Consortium. (2017). *NMC/COSN Horizon Report: K-12 edition*. Retrieved from https://cdn.nmc.org/media/2017-nmc-cosn-horizon-report-k12-EN.pdf

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

Novak, A., & Krajcik, J. (2004). Using technology to support inquiry in middle school science. In L. Flick & N. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 75-101). Dordrecht, NE: Kluwer.

Ottenbreit-Leftwich, A., Glazewski, K., Newby, T., & Ertmer, P. (2010). Teacher value beliefs associated with using technology: addressing professional and student needs. *Computers & Education, 55*, 1321-1335.

Patton, M. Q. (2014). *Qualitative research and evaluation methods: Integrating theory and practice*. Thousand Oaks, CA: Sage.

Polly, D. (2008). Modeling the influence of calculator use and teacher effects on first grade students' mathematics achievement. *Journal of Technology in Mathematics and Science Teaching, 27*(3), 245-263.

Polly, D. (2010). Preparing teachers to integrate technology effectively: The case of higher-order thinking skills (HOTS). In S. D'Augustono (Ed.), *Adaptation, resistance and access to instructional technologies: Assessing future trends in education*, (pp. 395-409). Hershey, PA: IGI Global. doi: 10.4018/978-1-61692-854-4.ch023.

Polly, D. (2011). Examining teachers' enactment of technological pedagogical and content knowledge (TPACK) in their mathematics teaching after technology integration professional development. *Journal of Computers in Mathematics and Science Teaching*, *30*(1), 37-59.

Polly, D. (2014). Deepening pre-service teachers' knowledge of technology, pedagogy, and content (TPACK) in an elementary school mathematics methods course. *Journal of Computers in Mathematics and Science Teaching*. *33*(2), 233-250.

Polly, D. (2015). Elementary education pre-service teachers' development of mathematics technology integration skills in a technology integration course. *Journal of Computers in Mathematics and Science Teaching*, *34*(4), 431-453.

Polly, D. (2016). Elementary education teacher candidates' development of lesson planning skills in an online instructional design course. *Journal of Applied Educational and Policy Research*, *2*(1), 12-23.

Polly, D., & Hannafin, M. J. (2011). Examining how learner-centered professional development influences teachers' espoused and enacted practices. *Journal of Educational Research*, *104*, 120-130.

Polly, D., & Rock, T. C. (2016). Elementary education teacher candidates' integration of technology in the design of interdisciplinary units. *Tech Trends: Linking Research & Practice to Improve Learning*, *60*(4), 336-343. doi:10.1007/s11528-016-0059-y

Richardson, K. W. (2009). *Looking at/looking through: Teachers planning for curriculum-based learning with technology* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3371354)

Scalise, K., Timms, M., Moorjani, A., Clark, L., Holtermann, K., & Irvin, P. S. (2011). Student learning in science simulations: Design features that promote learning gains. *Journal of Research in Science Teaching*, *48*(9), 1050-1078.

Schrum, L. (1999). Technology professional development for teachers. *Educational Technology Research and Development*, *47*(4), 83-90.

Smaldino, S., Lowther, D. L., Mims, C. D., & Russell, J. D. (2014). *Instructional technology and media for learning* (11th edition). New York, NY: Pearson.

Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*, 134-144.

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2008). *Teaching secondary school science: Strategies for developing scientific literacy* (9th ed.). Upper Saddle River, NJ: Prentice Hall.

U.S. Department of Education. (2016). *National education technology plan*. Retrieved from https://tech.ed.gov/netp/

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics*. Retrieved from https://www.ets.org/Media/Research/pdf/PICTECHNOLOG.pdf

Yoon, F. S., Ho, J., & Hedberg, J. G. (2006). Teachers as designers of learning environments. *Computers in the Schools, 22*(3/4), 145-157.