Abstract

Despite the growing popularity of digital teaching portfolios, research has remained focused on outcomes associated with *creating* digital teaching portfolios instead of examining how they can be used to effectively *assess* what teachers know, especially when it comes to educational technology. One barrier to using portfolios as a means of assessing teachers' knowledge of technology is the lack of a guiding framework for characterizing teachers' technology knowledge. In this paper, we propose that the Technological Pedagogical Content Knowledge (TPACK) framework is well suited to the task of studying the knowledge (including technological knowledge) teachers represent in their digital teaching portfolios. We demonstrate how the TPACK framework can guide a content analysis of digital teaching portfolios by analyzing 589 online portfolios created by educators as the culminating assessment in their master's studies. We conclude that the TPACK framework is helpful for analyzing the types of technological knowledge teachers may represent in portfolios but acknowledge several important challenges to its use.

Keywords: teaching portfolios, digital teaching portfolios, electronic teaching portfolios, internet-based research, Technological Pedagogical Content Knowledge, TPACK, assessment

What the Tech is Going on with Digital Teaching Portfolios? Using the TPACK Framework to Analyze Teachers' Technological Understanding

There is a long tradition of offering alternative forms of summative and formative assessment of pre- and in-service teachers through portfolios. Since the emergence of teaching portfolios in the 1980s, advocates have articulated their usefulness in diverse contexts and for varied purposes (Zeichner & Wray, 2001). Regardless of the particular context, teaching portfolios are considered to be an authentic medium for demonstrating teachers' abilities and skills. Just as artists display their skill by carefully choosing which works to feature in an art portfolio, teachers select for their teaching portfolios the artifacts that best indicate their educational skills, competencies, and craft (Moya & O'Malley, 1994).

More recently, portfolios that are expressed in online formats—called digital teaching portfolios or e-portfolios—have expanded the affordances of the portfolio beyond what traditional, paper formats offer. Digital teaching portfolios (the term we use to refer to all portfolios with a digital format or component) offer clear logistical and practical advantages for storage and representation and are also easier to share with evaluators, employers, peers, and other audiences (Pecheone, Pigg, Chung, & Souviney, 2005). Perhaps more importantly, digital teaching portfolios can store media that paper portfolios cannot (Oakley, Pegrum, & Johnston, 2014). Today's teachers can (and may be expected to) create their own teaching resources using technologies that were unavailable to or characterized by high barriers to entry for previous generations of educators, including videos, audio recordings, presentations, and animations. Whereas traditional paper portfolios cannot easily include videos and animations, digital teaching portfolios make it much more simple for teachers to embed them alongside other demonstrations of teacher knowledge.

For researchers, digital teaching portfolios that include newer, multimedia technologies provide largely unexplored possibilities to measure teachers' understanding and use of technology. That is, by examining what technologies teachers use (and how they use them) to build digital teaching portfolios and to represent their teaching, knowledge, and practice, researchers could examine those teachers' understanding of technology. Yet, *despite the potential to use portfolios to assess teachers' ability to teach with and otherwise use technology, teacher educators and researchers have largely overlooked the possibility of doing so.*

One possible barrier to considering portfolios as a means of assessing teachers' knowledge of technology may be the absence of a guiding framework for characterizing technology and the skills that teachers need to effectively integrate technology into their planning and teaching. We introduce the Technological Pedagogical Content Knowledge (TPACK) framework and propose that it is well suited to guide research on the knowledge and skills that teachers represent in portfolios, particularly their understanding of technology. By systematically describing seven components of knowledge that teachers need to possess in order to successfully teach with technology, the TPACK framework offers a comprehensive, yet understandable, approach to assessing knowledge.

In order to demonstrate its potential for analyzing digital teaching portfolios, we use the TPACK framework to examine 589 digital teaching portfolios created by educators between January 2011 and December 2014 as the culminating assessment in their master's degree studies. In doing so, we set out to both: (a) demonstrate how the TPACK framework may be used in practice to assess teachers' understanding of technology and (b) richly describe, categorize, and investigate a large sample of digital teaching portfolios.

Literature Review

Below, we summarize the extant research on both traditional teaching portfolios and digital teaching portfolios. From these reviews, we identify key gaps in the literature with respect to assessing technological understanding through portfolios. Accordingly, we introduce the TPACK framework as a proposed approach for assessing technological understanding and suggest how this framework may be explicitly applied to an analysis of digital teaching portfolios.

Research on Teacher Portfolios

Research on teaching portfolios has had two traditional foci. The first has treated portfolios as an assessment that is more authentic, comprehensive, and representative than traditional evaluations (Crow, Georgi, & Crowe, 1998; Wolf, 1991). In this research, traditional portfolios have been characterized as representations of pedagogical strategies, subject-matter knowledge, and Pedagogical Content Knowledge (PCK; Shulman, 1986). For example, in a recent study of science teachers' instructional strategies when incorporating the Next Generation Science Standards (NGSS), Hoffenberg and Saxton (2015) used teacher instructional portfolios including explicit pedagogical reflection prompts to qualitatively analyze the quality of teachers' pedagogical skills (PK) and content coverage (CK). The authentic nature of individual and school portfolios also offers an opportunity to assess teachers' beliefs and their translation to practice, a kind of study that also generally focuses on pedagogy and content (e.g., Craig, 2003; Donnelly & Boniface, 2013).

The second focus of research with portfolios has emphasized the ways in which they can inspire and guide reflection (Borko, Mihalec, Timmons, & Siddle, 1997). For example, Lyons (1998) found that portfolios could help teachers to develop the capability to reflect on their teaching. Teachers initially come with rudimentary understandings of reflective processes (e.g., reflection as "telling others"; p. 125) that over time and with facilitation (e.g., from portfolios) develop into a more elaborate view (e.g., reflection as "critical collaborative conversations"; p. 125). Once developed, these critical reflective skills can last long after the portfolio's completion (Lyons, 1998; Zeichner & Wray, 2001).

In summary, although portfolios have been traditionally used to ground authentic assessment of teachers' pedagogical strategies, subject-matter knowledge, Pedagogical Content Knowledge, and reflective processes, more recent efforts have explored additional affordances for portfolio-based assessment of teachers.

Research on Digital Teaching Portfolios

Researchers interested in *digital* teaching portfolios have maintained some of the trends that exist in the broader field of portfolio research. Like researchers of traditional portfolios, scholars have examined the potential of digital teaching portfolios to serve as learning portfolios (Strudler & Wetzel, 2005; 2011) and to foster the reflective processes involved in making such a portfolio. Although digital teaching portfolios are also held to support teacher reflections (Genc & Timnaz, 2010), research has shown that this may not occur without a great deal of instructional support (Oakley, Pegrum, & Johnston, 2014). For example, Sung, Chang, Yu, and Chang (2009) found that only one third of their teachers were reaching the highest levels of reflection.

Research on digital teaching portfolios has also expanded to include new considerations that previous portfolio research could not have included. For example, some scholars have focused on how making a portfolio develops teachers' understanding of technology (Herner, Karayan, McKean, & Love, 2003; Lin, 2008). By learning new software and technical skills (such as website design), teachers making portfolios have reported learning new technological skills (Evans, Daniel, Mikovch, Metze, & Norman, 2006), having more confidence in their technology skills (Milman, 2005), and being more likely to be able to learn new technologies (Lin, 2008) or incorporate technology into their teaching (Sherry & Bartlett, 2005; Wang & Turner, 2006). Developing a digital portfolio has also been shown to positively impact teachers' attitudes and openness to technology (McKinney, 1998), help them develop positive identities as technology learners (Trent & Schroff, 2013), and increase teachers' self-efficacy in using technology (Pecheone et al., 2005).

Other areas of research likewise focus on new implications of the digital aspect of teaching portfolios. For example, some researchers have focused on the technical requirements and competencies required to build a digital teaching portfolios (e.g., Barrett, 2008, Chatham-Carpenter, Seawel, & Raschig, 2010; Bolliger & Shepherd, 2011), including digital literacies (Hunt, Huijser, & Sankey, 2012). In a similar vein, several challenges, roadblocks, and barriers have been identified in the creation of digital portfolios, including access to needed hardware and software, unforeseen technical glitches, and additional time needs (Lopez-Fernandez & Rodriguez-Illera, 2009; McKinney, 1998; Milman, 2005; Moran, Vozzo, Reid, Pietsch, & Hatton, 2013). Finally, one group of researchers has examined the programmatic and administrative implications of implementing digital teaching portfolios (Strudler & Wetzel, 2005; 2006; Wetzel & Strudler, 2005).

As reviewed in the previous section, portfolios have traditionally been used to assess pedagogical understanding, subject-matter knowledge, and pedagogical content knowledge. With the advent of digital teaching portfolios, it stands to reason that these portfolios could also be used to assess understanding of technology. And yet, there is a notable absence of research exploring the *assessment potential* of digital teaching portfolios in terms of understanding the kinds of knowledge and skills that teachers chose to represent in their portfolios. Existing research into this area has been limited to case studies that, understandably, focus on qualitative examination of a few artifacts. For example, Moran and colleagues (2013) examined artifacts in digital teaching portfolios and found that they were “coherent”, “linked well to standards,” and “annotat[ed]” using the “language of the teaching standards,” and that “resourceful and innovative ICT skills were utilized” (pp. 126-127). Little examination of what specific “innovative ICT skills” are, exactly, currently exists in the digital teaching portfolio literature.

The TPACK Framework

One potential barrier to considering digital teaching portfolios as a means of assessing teachers’ knowledge of technology may be the lack of a guiding framework for thinking about characterizing the technology and skills that may be exhibited in digital teaching portfolios. We propose that the Technological Pedagogical and Content Knowledge (TPACK) framework is well suited to guide research about these knowledge and skills. The TPACK framework describes the intersections between content, pedagogical, and technology knowledge, offering both four dimensions of technology knowledge and a comprehensive, but understandable, approach to assessing digital teaching portfolios.

Building upon earlier work on the importance of teachers’ knowledge (Shulman, 1986), the TPACK framework elaborates how technology might relate to subject matter and how it is taught (Authors, 2006). According to this framework (Figure 1), teachers who effectively integrate technology employ seven types of knowledge:

- *Pedagogical Knowledge (PK)*: teachers’ deep knowledge about the processes and practices or methods of teaching and learning. This includes an understanding of overall educational purposes, values, and aims and applies to understanding how students learn, general classroom management skills, lesson planning, and student assessment.

- *Content Knowledge (CK)*: teachers' knowledge about the specific subject matter to be learned or taught. As Shulman (1986) noted, this knowledge includes concepts, theories, ideas, organizational frameworks, evidence and proof, as well as established practices and approaches toward developing such knowledge.
- *Pedagogical Content Knowledge (PCK)*: consistent with and similar to Shulman's (1986, 1987) formulation, the transformation of the subject matter for teaching. Specifically, according to Shulman (1986), this transformation occurs as the teacher interprets the subject matter, finds multiple ways to represent it, and adapts and tailors the instructional materials to alternative conceptions and students' prior knowledge.
- *Technology Knowledge (TK)*: a broad understanding of information technology and computer literacy. This form of knowledge allows teachers to productively use technology at work and in their everyday lives, to recognize when information technology can assist or impede the achievement of a goal, and to continually adapt to changes in information technology.
- *Technological Pedagogical Knowledge (TPK)*: an understanding of how teaching and learning can change when particular technologies are used. This includes knowing the pedagogical affordances and constraints of a range of technological tools as they relate to disciplinarily- and developmentally-appropriate pedagogical designs and strategies.
- *Technological Content Knowledge (TCK)*: an understanding of the way technology and content influence and constrain one another. TCK allows teachers to understand which

specific technologies are best suited for addressing subject-matter learning in their domains as well as how the content dictates or perhaps even changes the technology.

- *Technological Pedagogical Content Knowledge (TPCK)*: an understanding that emerges from interactions among content, pedagogical, and technology knowledge. TPCK includes an understanding of the representation of concepts using technologies, pedagogical techniques that use technologies in constructive ways to teach content, and knowledge of what makes concepts difficult or easy to learn with various technologies.

Acknowledging the importance of the myriad of settings in which teachers carry out their instruction, each of these forms of knowledge is situated in classroom, institutional, district, and state contexts (Authors, 2015c).

The TPACK framework—especially the aspects related to technology knowledge—is a reasonable starting point for exploring the knowledge because of both its conceptual clarity and the utility it has provided for others. Specifically, because the TPACK framework focuses on the knowledge base needed for teaching, it provides an intuitive means of conceptualizing and organizing areas of teacher knowledge, including knowledge represented in portfolios. Furthermore, these intuitive connections are bolstered by a history of application, including programs of in-service and pre-service professional development (Harris, 2016; Mouza, 2016), effective classroom instruction (Hofer, Bell, & Bull, 2015), measurement of teachers' understanding of technology (Archambault, 2016; Chai, Koh, & Tsai, 2016), and even teachers' reflective processes while creating portfolios (Chui, Au-Yeung, & Cheng, 2015).

Using the TPACK Framework to Understand the Knowledge Represented in Portfolios

Using the TPACK framework as a lens to examining portfolios allows us to summarize what kinds of knowledge portfolio researchers have already examined and what kinds have yet to be studied. For example, previous research about traditional portfolios can be summarized as chiefly focused on considerations of PK, CK, and PCK. Some research has also focused on the technology knowledge (TK) that teachers acquire while making a portfolio or that teachers need in order to make a digital teaching portfolio; however, these studies have relied largely on self-reported data and have not used the digital teaching portfolios as a source of evidence of understanding.

However, just as the TPACK framework can be used to describe those kinds of knowledge already studied, we propose that it can also be used to guide future scholarship around portfolios. Specifically, we propose that portfolios can be used to document knowledge corresponding with the TK, TCK, TPK, and TPCK components of the TPACK framework. A natural starting point for analyzing evidence for these components in teacher portfolios would be to analyze the *artifacts* teachers decide to include as evidence of their teaching skill. In this context, the term *artifact* refers to any document or file contained within the portfolio that demonstrates knowledge: This includes text, video, graphic, and presentation files.

In our proposed approach, TK—or the ability to work with technological tools and resources—is best assessed by looking across all artifacts to see what technological tools and resources teachers bring to bear in presenting their digital teaching portfolios. Practically, this means coding each artifact for the technology used and looking across those codes to determine:

- what kinds of technologies teachers can use effectively (or do not use), and
- whether teachers are flexible enough to use different technologies in their portfolios.

Teachers with higher levels of TK should, we hypothesize, be able to use multiple types of technology and use them effectively given the great variety in contexts, goals, and subject-matter concerns that teachers raise in their digital teaching portfolios.

To study TCK, TPK, and TPCK, we use a rubric developed during a pilot study (Authors, 2014). This *TPACK Artifact* rubric was first developed by Harris, Grandgenett, and Hofer (2010) for assessing teachers' lesson plans; we deemed it to be the best starting point for analyzing portfolio artifacts because of its high reliability and validity as well as its flexibility for looking across subject-matter areas. Our revised TPACK Artifact rubric can be seen in Table 1. Using the rubric, raters can score artifacts on each dimension (TCK, TPK, and TPCK), ranging from low (1) to high (4).

Our previous experiences suggest that this rubric worked best with "rich artifacts"—a term that will be used throughout this paper to refer to artifacts that have teachers *explicitly* consider or discuss the connections between content, pedagogy, and technology. For example, the video a teacher used to teach a math concept to students was not considered rich, because teachers did not provide any reasoning about *why* video was chosen as a good medium for teaching that concept. Video may have been chosen as a technology for sound or unsound reasons. In contrast, a video with accompanying lesson plan that addressed why certain technologies were selected and what pedagogies were emphasized would be considered a "rich artifact."

Our pilot study showed that when this rubric was applied to on *every* artifact using technology inter-rater reliability was very low. In these instances, raters essentially are left to make (unreliable) inferences about connections between content, pedagogy, and technology when the teachers do not state these connections. When rich artifacts were used, however, the inter-rater reliability of the rubric is considered *moderate*, with weighted Cohen's kappa ranging between .45 and .55 in the present study.

Purpose and Research Questions

In order to demonstrate the potential of using the TPACK framework to analyze portfolios, we analyzed 589 digital teaching portfolios created by educators between January 2011 and December 2014 as the culminating assessment in their master's studies. We describe, categorize, and investigate these portfolios—and the artifacts therein—in terms of their creators' technological understanding. The following four research questions guide our approach:

1. What understanding of Technology Knowledge (TK) do teachers show in the Web platforms they chose for their portfolios and in the artifacts comprising their digital teaching portfolios?
2. What understanding of Technological Pedagogical Knowledge (TPK) do teachers show in the artifacts comprising their digital teaching portfolios?
3. What understanding of Technological Content Knowledge (TCK) do teachers show in the artifacts comprising their digital teaching portfolios?
4. What understanding of Technological Pedagogical Content Knowledge (TPCK) do teachers the artifacts comprising show in their digital teaching portfolios?

Answers to these four questions will allow us to evaluate the suitability of using the TPACK framework to assess technology understanding present in portfolios.

Context and Setting: The Capstone Portfolio Course

Before describing our methodological approach for this study, it is first necessary to describe its context and setting. Digital teaching portfolios is a broad term that applies to a general set of reflective processes and alternative assessment practices that allow teachers to demonstrate skills, knowledge and competencies (Authors, 2015b). Considerable variation exists among these approaches when these broad themes are applied to specific implementations. We therefore use this section to contextualize our own experiences with digital teaching portfolios not only to better ground our own work within the variation of portfolio approaches but also to better situate where the data in this study is drawn from.

Since 2010, the authors have taught the *Capstone Portfolio Course* as part of the accredited Master of Arts in Education (MAED) and Master of Arts in Educational Technology (MAET) programs at a large, land-grant, Midwestern University. The MAET is a mostly online (yet with some hybrid and face-to-face opportunities) graduate educational technology degree, and the MAED program is an all-college, fully online, graduate education degree. Participants in the MAED program take general education courses, including 9-credit specializations about topics such Science and Mathematics Education, Special Education, and Technology and Leadership. Whereas educational technology is a focus for MAET students, it is largely a context for MAED students who experience most of their program via educational technology.

Both MAED and MAET students must enroll in the *Capstone Portfolio Course* as a program-culminating experience in order to graduate. The main activity driving the course is the design and implementation of a digital teaching portfolio. The course is structured into one- to-two-week modules that scaffold the processing of designing a portfolio and populating it with teaching and learning artifacts. A rough outline of the modules (and associated goals) common to all students is included in Table 2. The assignments—and their order—have changed slightly from year to year; Table 2 therefore represents the assignment sequence from one sample semester, to show how the course pieces fit together.

Out of necessity, this description is overly reductive and missing many details. Interested readers may find more detail in our previous writings (Authors, 2015a; Authors, 2015b) or through an examination of the current version of the course, which is publically available (URL removed for blind review) and includes links to students' portfolios.

Capstone portfolios have much in common but also display great diversity—what Strudler and Wetzel (2011) call a balance of pre-prescribed and self-selected artifacts. On one hand, there is considerable structure to the portfolio, as students must complete many of the same required portfolio elements (e.g., each must have a resume, a showcase page, etc.). On the other hand, students are encouraged to show creativity and personality in how they satisfy each requirement. For example, they are free to choose what artifacts to present on their "showcase" page (and accordingly, what skills to highlight). They are encouraged to develop their own style, layout, and voice for presenting these artifacts. The result is that no two showcase pages look alike. Moreover, during the technology exploration phase of the course (modules 2 and 3), students are presented with a wide range of popular Web-building tools and activities that encourage exploration of different possibilities. The decision about what Web-authoring platform to use is up to each individual student. We only ask that they explore multiple platforms and thoughtfully compare their affordances and constraints before settling on one.

The two biggest components of the portfolio in terms of grading and time commitment are the synthesis reflection (module 9) and showcase (module 6). Conceptually, this aligns well with the traditional functions of a portfolio in terms of a space for reflection and a showcase of knowledge and skills. In the present study, the showcase page features prominently in the data collection. Accordingly, we provide a somewhat extended example of a showcase in Figure 2. This student has chosen to illustrate three key themes of knowledge in skill in the portfolio page: research, empathy, and ideation. For each, he has provided three example artifacts (each large image is a link to an artifact) along with a short text description of and reflection on that artifact. In this example, 6 of the artifacts are course assignments saved as PDF text documents, and three are to links of YouTube videos.

Of all the possible artifacts educators could put on their showcase page, two specific artifacts, both from the *MAET program only*, afforded special windows into teachers' thinking about how technology might be used in their teaching. That is, these two artifacts were considered "rich artifacts" such that the rubric (Table 1) could be applied to explore the connections between content, pedagogy, and technology.

- *DreamIT*: A grant proposal focused on the thoughtful integration of a technology into teaching and learning. As part of their proposal, teachers explicitly consider TPACK when describing how the technology will be used in practice. In addition, the assignment emphasizes the importance of tailoring the grant proposal for the context in which teachers function.
- *Learning Technology Initiative (LTI)*: A proposal for a technology-integrated solution to a problem of practice, a difficult-to-solve issue that teachers face in their occupations. Teachers explicitly consider each of the seven components of TPACK when completing a table that specifies what knowledge teachers would need when implementing this solution. The proposal also emphasizes the contextual factors that need to be considered in order for the initiative to be a success.

In summary, through the combination of common elements and individuality, educators who complete the capstone portfolio course end up with a unique digital teaching portfolio that reflects their own personality and experiences yet meets all program requirements in either the Master of Arts in Education (MAED) and Master of Arts in Educational Technology (MAET) programs.

Method

For this study, we analyzed data from 589 digital teaching portfolios using content analysis of the knowledge represented in those portfolios, including the artifacts these portfolios contained. We coded data qualitatively according to categorical schemes and prepared quantitative summaries of that data, such as frequency counts and proportions of data by coding category. When noticeable differences appeared in the descriptive data, we present appropriate statistical tests to help place further meaning on the magnitude and potential importance of any effect.

Data Sources

Portfolios. Primary data comes from 589 online portfolios created by students enrolled in the capstone portfolio course of the MAET and MAED programs between January 2011 and December 2014. This represents all portfolios available using the current course format at the time data analysis began. Approximately 70% of these students are practicing teachers in K-12, higher education, pre-school, and other educational settings spanning all subject-matters. The remaining 30% of students represent other educational careers such as technology coordinators, school administrators, and coaches. Throughout the remainder of this study, we refer to all portfolio creators as educators to emphasize their completion of digital teaching portfolios and their professional qualifications in the field of education.

Artifacts. We selected a sample of artifacts for further analysis by randomly selecting 72 portfolios (6 portfolios from each of the 12 semesters of the course). We then identified all of the artifacts on the homepages, transcript pages, and showcase pages (n = 895) to use in our analysis.

DreamIT and LTI artifacts. All DreamIT (n = 52) and LTI (n =1) artifacts that were included in educators' portfolios during the study period (2011 through 2014) were analyzed. Note that educators decided what artifacts to include in their portfolios, and that DreamIT and LTI artifacts applied only to educators enrolled in the MAET program. DreamIT artifacts were included in 8.8% of all portfolios, and only one LTI artifact was included (0.2% of all portfolios).

Measures

Several measures were derived for an analysis of the technologies that educators used to create their digital teaching portfolios, the artifacts they included within their portfolios, and the included DreamIT and LTI artifacts. We list these measures below, along with a brief description of each, including an identification of what form of knowledge each corresponds to.

Portfolio platform. The Web-authoring platforms (i.e., technologies that educators used to create their portfolios) were coded using the *portfolio platform* measure of TK. A random sample of 60 portfolios (approximately 10% of the total) was coded by a second rater to establish inter-rater reliability (Cohen's kappa = .90; *almost perfect*).

Artifact technology. All 895 artifacts in the sample were coded according to the technologies used to create each artifact in the sample (e.g., video, text, spreadsheet) with the *artifact technology* measure of educators' TK. An initial coding scheme became saturated at 40 codes and was reduced into the 7 broader categories summarized in Table 3. Three raters applied this coding scheme to 50 artifacts to establish the reliability properties of the scheme (Fleiss's kappa = .98; *almost perfect*).

Technology flexibility. The *technology flexibility* measure of educators' TK was computed as the number of different kinds of technologies (of the seven in Table 3) present in each portfolio. For example, a portfolio that only contained artifacts coded as Word Processing Technologies received a score of one for *technology flexibility*. In contrast, a portfolio that contained Word Processing, Social Media, and Presentation artifacts received a score of three.

Levels of TCK, TPK, and TPCK. The "rich artifacts" that explicitly had educators consider connections between content, pedagogy, and technology (i.e., the *DreamIt* and the *LTI*), were analyzed with the *Levels of TCK, TPK, and TPCK* measure (Table 1), which assessed those technology-related aspects of TPACK not addressed by the previous measures. Two coders rated each artifact to establish reliability (Cohen's kappa ranged between .45 and .55 on the three dimensions, suggesting *moderate* reliability).

Results

We present our results as they correspond to TK, TPK, TCK, and TPCK, the four components of the TPACK framework that explicitly touch on knowledge related to technology.

Technology Knowledge (TK)

Technology Knowledge (TK) was assessed three ways in this study: an analysis of the *portfolio platform* educators used to create their portfolios, an analysis of the *artifact technology* educators used within their portfolio artifacts, and a measure of *technology flexibility*.

A quality measure of Technology Knowledge should be sensitive to differences in educators who have more or less understanding and experience with technology. In our sample, that means that properly functioning measures of TK should distinguish between educators in the

MAET (educational technology) and MAED (general education) programs. We test this hypothesis when examining our three measures of TK by looking for differences between MAET- and MAED-enrolled educators.

Portfolio Platform. Educators used a variety of platforms, including Weebly, Wix, WordPress, and several others. However, within this variety, there were some clear preferences. Weebly accounts for 373 portfolios (63% of the sample), and Wix accounts an additional 125 (21%). In contrast, WordPress only accounted for 28 portfolios (5% of the sample), 45 portfolios (8%) were built on other, less-common platforms, and 18 portfolios (3%) used platforms that could not be identified. A chi-square goodness of fit test confirms that this distribution is significantly different than what would be expected from random chance ($\chi^2[4] = 751.3$, $p < .001$). There are also changes over time in the proportion of portfolios built using each platform (see Figure 3). Notably, Wix became more popular over time, as confirmed by a logistic regression analysis ($\beta = 0.71$, $z = 6.77$, $p < .001$).

The very existence of these teaching portfolios serves as a tacit but important evidence of educators' basic technology knowledge. That 589 educators were able to create a Web-based digital teaching portfolio using a diverse set of platforms and without receiving explicit instruction on Web design suggests that they possessed technology knowledge that was not common among teachers fifteen years ago. This is even more impressive given that many of these 589 educators were not enrolled not in an educational technology program and that the capstone portfolio is the first website that many of these MAED educators (and even some MAET educators) created.

Artifact technology. Throughout the four years in the sample, five different *artifact technologies* were used frequently (see Table 3). Document Presentation/Storage (i.e., chiefly

PDF) technologies were the most popular (representing 39% of all artifacts), but other technologies, including Web (23%), Multimedia (16%), Word Processing (12%) and Presentation (6%) technologies, were also frequently used. Moreover, the pattern of technology usage changes over time, as confirmed by follow-up logistic regression analyses. Three types of technology were used more frequently over time: Web ($\beta = 0.21$, $z = 2.92$, $p < .01$), Presentation ($\beta = .26$, $z = 2.07$, $p < .05$), and Other ($\beta = 0.47$, $z = 1.96$, $p < .05$). Two categories of technology—Document Presentation/Storage ($\beta = -0.12$, $z = -1.96$, $p < .05$) and Word Processing ($\beta = -0.62$, $z = -5.76$, $p < .001$)—were used less over time.

Furthermore, as can be seen in Table 3, this measure demonstrates differences by program. Educators in the Educational Technology program (MAET) were significantly more likely than their Education (MAED) counterparts to use Web, Social Media, Multimedia, and Presentation technologies and significantly less likely to use Document Presentation/Storage technologies. Educators in both programs, however, were equally likely to use Word Processing and Other technologies to display artifacts in their portfolio. These results are encouraging, as there should be differences in a TK measure between educators enrolled in an educational technology program rich with technology uses and instructional practices (i.e., MAET) and those in one that has less of a focus on technology (i.e., MAED).

Technology flexibility. Our final measure of educators' TK, *technology flexibility*, focuses on the number of different technologies they used to represent artifacts. The average portfolio used 3.47 different technologies, indicating a fair amount of flexibility. That is, on average, educators are using (and demonstrating skill with) more than three different types of technology to represent artifacts. However, educators in the MAET program used a mean of 4.05 (SD = 1.37) different technologies compared to just 2.82 (SD = 1.21) within the MAED program

($t[67.99] = -4.00$, $p < .001$). This difference between programs is also seen as encouraging, as it points to a measure of TK that appropriately distinguishes between educators with more (MAET) and less (MAED) technology skills and experiences.

Levels of TPK, TCK, and TPCK

Analysis of the DreamIT and LTI artifacts represented an opportunity to examine the way that educators enrolled in MAET classes think about how technology might be used in educational practice. Because both of these artifacts ask educators to make connections between technology, curriculum, and pedagogy, these artifacts present an opportunity to analyze the extent to which their creators demonstrate TPK, TCK, and TPCK.

Using the proposed TPACK artifact rubric (Table 1), raters scored each of the 52 DreamIT and LTI artifacts in this analysis along the TPK, TCK, and TPCK dimensions. Table 4 presents the mean, standard deviation, and distribution of scores for the TPK, TCK, and TPCK scales used to rate the 48 DreamIT and LTI artifacts in this analysis. The range of the mean scores—between 2.78 and 2.90—suggests that, on average, educators are displaying some intermediate understanding of TCK, TPK, and TPCK. For example, they are choosing, on average, technologies that are only “partially aligned” with curricular goals (TCK). There are, however, individual differences as artifact scores span the range of 1 through 4 across all measures.

Discussion

In order to demonstrate the potential of using the TPACK framework to analyze portfolios, we analyzed 589 digital teaching portfolios and a sample of the artifacts they contained. This exploration helped reveal both positive and negative aspects regarding the suitability of using the TPACK framework to assess technology understanding in portfolios and artifacts; we explain these aspects in the sections that follow.

Measuring Levels of TK, TCK, TPK, and TPCK

Using our approach, we were successful in measuring each of the technology components of the TPACK framework (TK, TCK, TPCK, and TPCK). We found that educators possessed a strong base of basic technology knowledge (TK), as evidenced by the diversity of technologies used to create these portfolios and corresponding artifacts. Not only did educators use a variety of platform technologies, they also used an average of at least three different artifact technologies in their portfolios. Beyond this quantitative analysis, an inspection of specific technologies suggests that educators move towards richer and more diverse technologies over time. For example, there was a significant decrease in Document Presentation/Storage and Word Processing artifacts, and a corresponding increase in Web, Presentation, and Other artifacts over time.

Our approach was also able to measure levels of TCK, TPK, and TPCK when “rich artifacts” (i.e., the DreamIT and LTI artifacts) were present. In contrast to high levels of TK, levels of TCK, TPK, and TPCK components were more moderate. This pattern, however, is understandable given that educators’ development of these interconnections requires extensive immersion and time (Authors, 2007) and that other studies of in-service teachers’ level of TPACK (Archambault & Crippen, 2009) reported similar results.

Measurement Properties of a TPACK Approach

The second affordance of using the TPACK framework to assess technology knowledge comes from an examination of the measurement properties of this approach. In terms of reliability, the proposed coding schemes for the *portfolio platform*, *artifact, technology flexibility* (measures of TK) were all highly reliable, and straightforward enough to be applied to 589 portfolios and 895 artifacts. The coding scheme for the *Levels of TCK, TPK, and TPCK* measures showed sufficient reliability (albeit less than the TK measures). In addition, we easily applied the coding scheme to the 52 DreamIt and LTI artifacts in our sample. Moreover, the underlying rubric was derived from an existing measure with established reliability and validity properties (Harris, Grandgenett, & Hofer, 2010).

The measures for TK also successfully distinguished between educators in the MAED (general education) and MAET (educational technology) programs. Because these groups have significant differences in their technological background and experiences, they should differ on measures of technology knowledge. In the present study, measures of TK (*artifact technology* and *technology flexibility)* correctly suggested higher levels for educators enrolled in the educational technology program (MAET). These findings lend support to our conclusion that the TK measures proposed in this approach are well suited to characterizing educators' levels of technological knowledge.

The Need for "Rich Artifacts"

One major hindrance to using the TPACK framework to assess technology understanding is the requirement for "rich artifacts" to examine educators' understanding about the connections between content, pedagogy, and technology. Indeed, the artifacts we analyzed using the TPACK artifact rubric were those that were explicitly informed by TPACK and that explicitly addressed the framework. Given what educators created during the MAET and MAED program and included in their portfolios, this meant finding instances of the "rich artifacts" called DreamIt and LTI. For other programs, this might mean lesson plans, reflective essays, grant proposals, or other artifacts that ask for deeper (or more explicit) reflections about the role of technology.

In the present study, this issue is underscored by how infrequently educators chose to include the DreamIT artifact (in 8.8% of portfolios) and LTI artifacts (0.2% of portfolios). Even though nearly every educator created these artifacts at some point in their MAET program, and though these artifacts have the most potential to demonstrate educators' deeper understanding of technology through the connections between technology, content and pedagogy, educators appear to have been reluctant to include them.

Implications for Future Research

This work has important implications for teacher educators or teacher educator programs seeking to characterize how their candidates understand educational technology. To date, approaches to assessment of digital teaching portfolios have been idiosyncratic, as different programs look for different things from their candidates, a diversity that reflects varying contexts, coursework, and values (Studler & Wetzler, 2011). The TPACK framework, in contrast, suggests a parsimonious way of identifying important aspects of educational technology knowledge. In identifying TK, TCK, TPK, and TPCK as markers of deep understanding, it suggests that it is worth the time and attention to assess each of these components. As seen in the present study, the TPACK framework appears able to characterize the not only the technical skills (TK) educators brought to bear in building online portfolios, but also how those skills relate to the subject matter (TCK), pedagogical concerns (TPK), and teaching (TPCK).

The work of applying the TPACK framework to digital teaching portfolios, however, is not without challenges. In order to assess the components of the TPACK framework, artifacts must include enough of educators' reasoning that evaluators can understand how they see connections between content, pedagogy, and technology. That is, applying the TPACK framework to digital teaching portfolios requires the inclusion of some "rich artifacts" within portfolios. Teacher educators may have to prescribe specific artifacts, or requirements for artifacts, in order to meet this "richness" threshold. This is supported by Strudler and Wetzel's (2011) suggestion that programs "balance prescribed and self-selection of artifacts" (p. 169) indicating that there are benefits for having prescribed artifacts that meet the needs for assessment and self-selected artifacts that allow students to document their own learning.

There are also implications of this study for further TPACK research. The suitability of the TPACK framework for measuring the technological knowledge underlying the artifacts contained in digital teaching portfolios lends support to the utility of the framework for characterizing educators' technology knowledge in a growing number of settings. Measurement issues, however, suggest more work needs to be done, especially in the area of establishing increasingly reliable and valid measures of TCK, TPK, and TPCK, especially in artifacts (Authors, 2013).

Limitations of the Study

One limitation of this study was that the rubric measuring TPK, TCK, and TPCK was considered *moderately* reliable (Landis & Koch, 1977), whereas the three measures of TK were found to be very highly reliable. While this represents a considerable improvement over our initial pilot study using an earlier version of the rubric and artifacts less suitable to analysis, future work can (and should) focus on further modifying the rubric (and/or requirements for the artifacts) to further raise the reliability of this approach.

Another limitation of this study is the low inclusion rate of "rich artifacts" in our sample. We suspect the low rates of inclusion stem from a preference of the educators in our sample to include more artifacts that were easier to summarize and present instead of presenting a few artifacts that were more complex in nature. It is also possible that educators' hesitance to use more complex artifacts may be indicative of their lack of confidence in their knowledge and their limited knowledge of the interconnections of TPACK. Practically, this represents a disconnect between program goals to have educators do the more complicated and important work represented in the DreamIT and LTI artifacts and educators' reluctance to showcase that work.

The sample in this study was limited to portfolios from master's students in education. Not all portfolios in this study came from practicing teachers—30% of educator portfolios represented diverse careers spanning technology coordinators, school administrators, and coaches. This sample may not extend reliably to pre-service teachers or the digital portfolios they create.

A final limitation of this approach to assessing teachers' technological understanding is that it that it does not consider what teachers might know but do not demonstrate on their individual portfolios. For example, a teacher may very well be proficient in the use of digital video technologies, but not include a video within their portfolio. In this approach, without any "digital traces" (Welser, Smith, Fisher, & Gleave, 2008) of this knowledge (i.e., a video) in the portfolio, there is no assumption that teachers have this skill. Researchers and practitioners concerned with this limitation may wish to consider structuring portfolio assignments that encourage teachers to include as many technology types as possible (e.g., "If you have a good video example of your thinking, this might be a good place to include it on your portfolio.").

Conclusion

The TPACK framework was originally designed for the purpose of "identifying objects worthy of attention in the phenomena that we are studying" and "highlighting relevant issues and ignoring irrelevant ones" (Authors, 2006, pp. 1043-1044). In this paper, we have examined the utility of the TPACK framework for analyzing and interpreting educators' understanding of technology as evidenced in their digital teaching portfolios. We were able to identify patterns in educators' knowledge suggesting that they possess a strong base of technology knowledge and that they have moderate levels of higher-order forms of technology knowledge (i.e., TCK, TPK, and TPCK). Our ability to make these determinations with the TPACK framework gives us confidence that this framework can serve as a useful lens for understanding the forms of knowledge found in other teachers' portfolios. Indeed, the use of the TPACK framework may help realize the potential of digital teaching portfolios as evaluations that help teacher educators, administrators, and researchers understand teachers' knowledge and skills in an authentic manner.

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Table 1

TPACK Artifact Rubric

Criteria	**4**	**3**	**2**	**1**
Curriculum Goals & Technologies: Curriculum-based technology use (TCK)	Technologies selected for use are strongly aligned with one or more curriculum goals.	Technologies selected for use are aligned with one or more curriculum goals.	Technologies selected for use are partially aligned with one or more curriculum goals.	Technologies selected for use are not aligned with any curriculum goals.
Instructional Strategies & Technologies: Using technology in teaching/ learning (TPK)	Technology use optimally supports instructional strategies.	Technology use supports instructional strategies.	Technology use minimally supports instructional strategies.	Technology use does not support instructional strategies.
Technology Selection(s): Compatibility with curriculum goals & instructional strategies (TPCK)	Technology selection(s) are exemplary, given curriculum goal(s) and instructional strategies.	Technology selection(s) are appropriate, but not exemplary, given curriculum goal(s) and instructional strategies.	Technology selection(s) are marginally appropriate given curriculum goal(s) and instructional strategies.	Technology selection(s) are inappropriate given curriculum goal(s) and instructional strategies.

Note. Modified from the Harris et al. (2010) TIAI-Adapted Rubric

Table 2

Capstone Portfolio Modules, Goals, Activities, and Products

Module(s)	**Goals, Activities, and Products**
0 - 1	**Exploration and Learning**: Educators review portfolios made by previous cohorts and make an informal list of features they would like to include in their portfolio.
2 - 3	**Portfolio Design**: Educators design their initial website, including layouts and menus, and make their initial homepage
4	**Reflection on Program Goals**: Educators write a reflective essay about how their learning goals have changed throughout their degree program and post it to a webpage in their portfolio.
5	**Establishing Professional Presence**: Educators add a resume, CV, or equivalent to a webpage in their portfolio to connect their experience to their professional community.
6	**Showcasing Skills**: Educators reflect upon their learning experiences and design a showcase page that shows artifacts—and annotations—documenting their knowledge, skills, and abilities.
7	**Reflection on Future Goals**: Educators write a reflective essay about their learning goals after the program is over and post it to a webpage in their portfolio.
8	**Annotated Transcript**: Educators design a webpage that lists courses taken and describes experiences gained from those courses.
9	**Synthesis Reflection**: Educators write a reflective essay considering what they have learned across their entire coursework and post it to a webpage in their portfolio.
10 - 12	**Peer Feedback and Presentations**: Educators finish up the course and their portfolios and participate in several rounds of peer and instructor feedback, including small-group presentations.
1 - 12	**Portfolio Customization**: Educators add three or more pages to their portfolios that contribute individual breadth and depth; these pages may include a blog, a teaching philosophy, or examples of student work.

Table 3.

Proportion of Artifacts by Technology and Master's Program

Artifact Technology	Description	Overall *N* = 895	MAED *n* = 453	MAET *n* = 442	Difference
Web	The artifact is a course management system, wiki, email address, or other Web platform.	.23	.11	.35	-.23 ***
Social media	The artifact is an account on Facebook, Twitter, or other social networking site.	.02	.01	.04	-.03 *
Multimedia	The artifact is an image, an audio recording, or a video.	.16	.08	.24	-.16 ***
Word processing	The artifact is associated with a traditional or Web-based word processor.	.12	.12	.11	-.01
Document presentation	The artifact is a PDF (or similar file) or hosted on a service (e.g., Google Drive) meant for storing or presenting documents	.39	.63	.14	.49 ***
Presentation	The artifact is a slide show file or is hosted on a slide sharing service.	.06	.03	.10	-.07 ***
Other	The artifact takes some other form.	.02	.01	.02	-.01

* $p < .05$, ** $p < .01$, *** $p < .001$ as assessed using a two-sample test of proportions.

Table 4

Proportion of DreamIT and LTI artifacts by TPACK Category and Level

Level	**TCK**	**TPK**	**TPCK**
1	.06	.00	.02
2	.33	.31	.37
3	.38	.48	.40
4	.23	.21	.21
Mean	2.79	2.90	2.81
Std. Dev.	.87	.72	.79

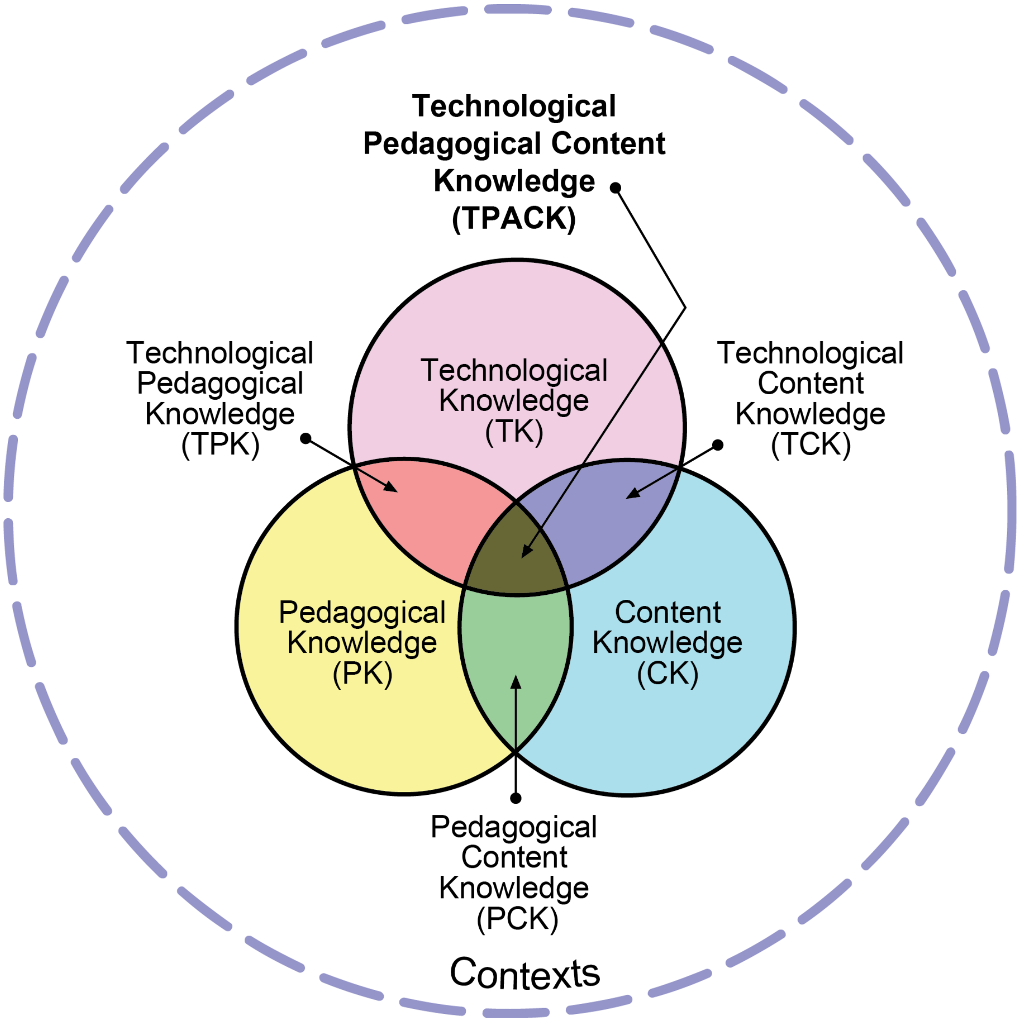

Figure 1. The components of the TPACK Framework [Reproduced by permission of the publisher, © tpack.org]

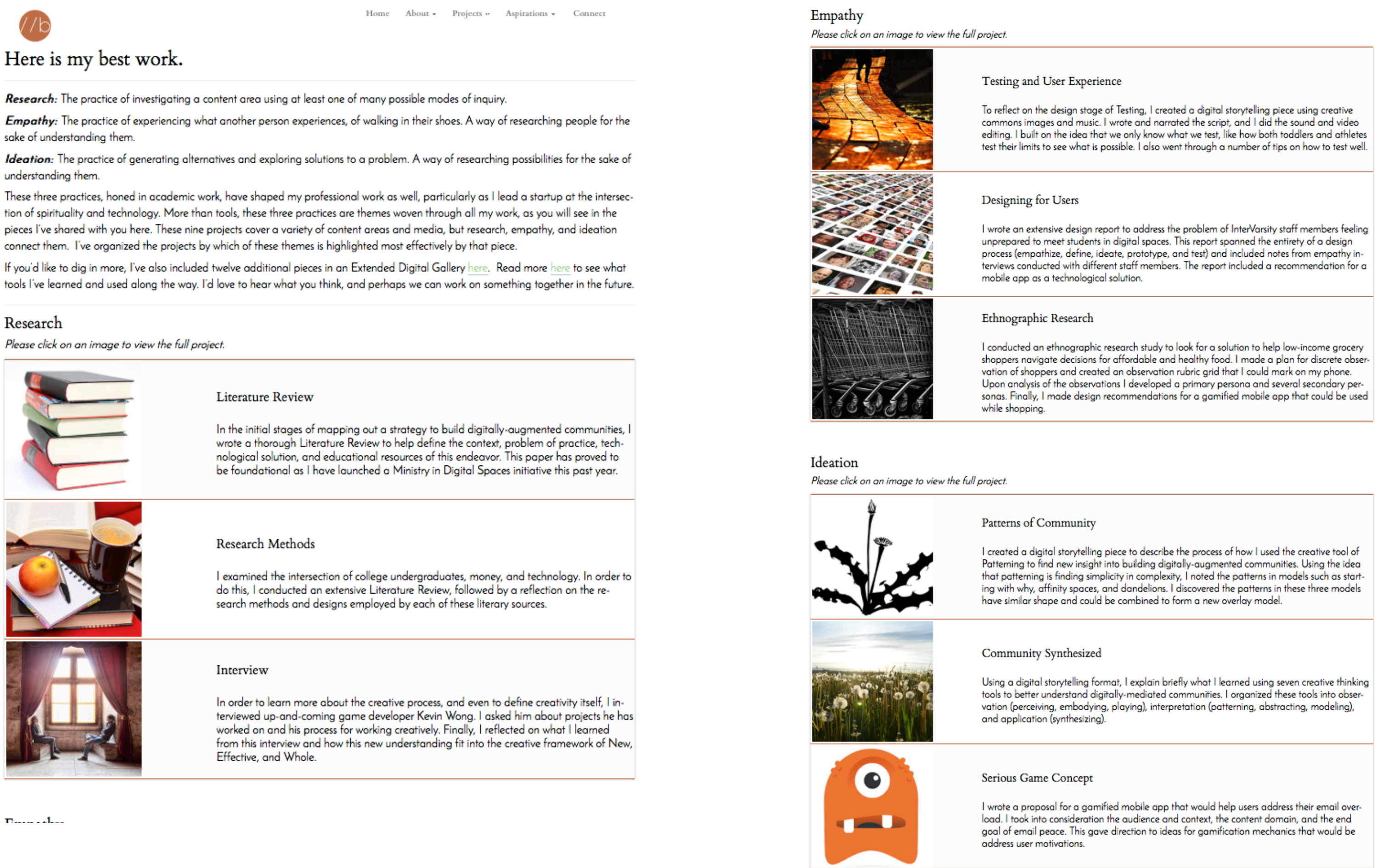

Figure 2. A sample showcase page

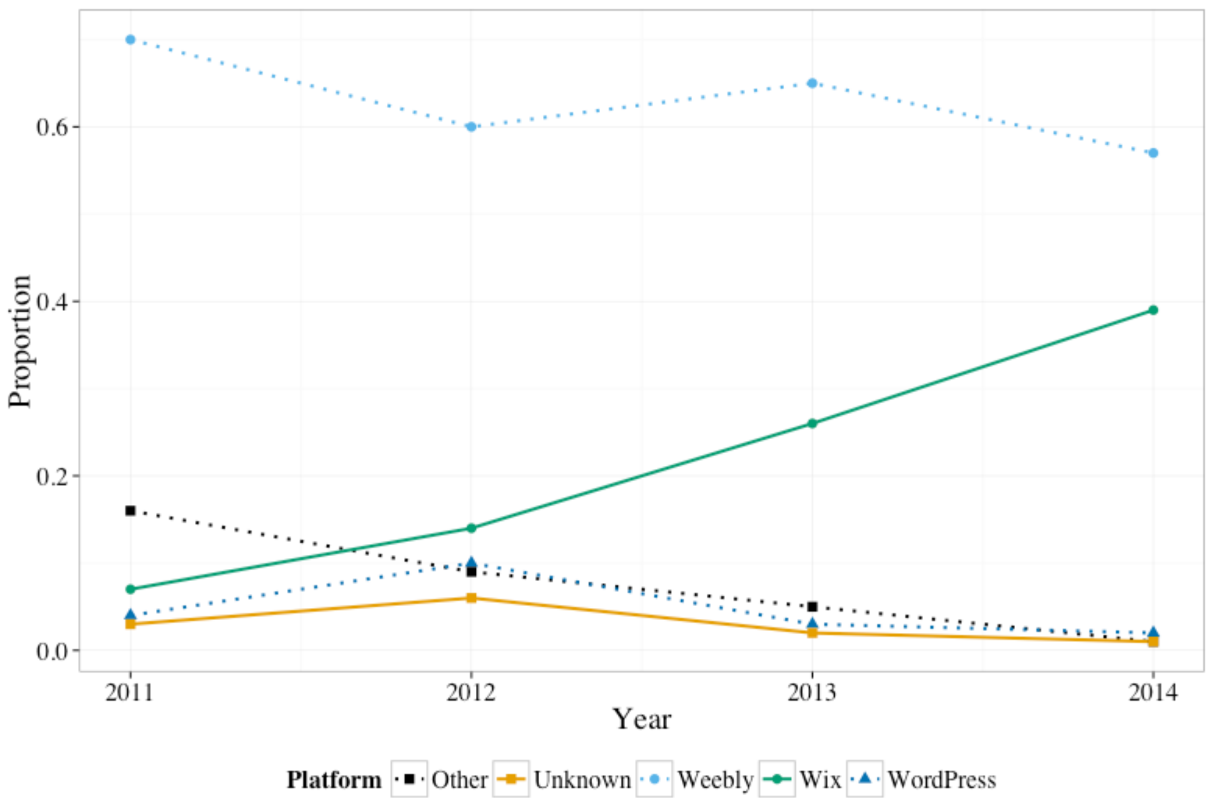

Figure 3. Proportion of portfolios by platform and calendar year