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RESEARCH ARTICLE

Comparing technology-related teacher professional development designs: a multilevel study of teacher and student impacts

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Abstract This article presents a quasi-experimental study comparing the impact of two technology-related teacher professional development (TTPD) designs, aimed at helping junior high school science and mathematics teachers design online activities using the rapidly growing set of online learning resources available on the Internet. The first TTPD design (*tech-only*) focused exclusively on enhancing technology knowledge and skills for finding, selecting, and designing classroom activities with online resources, while the second (*tech* + *pbl*) coupled technology knowledge with learning to design problem-based learning (PBL) activities for students. Both designs showed large pre-post gains for teacher participants ($N = 36$) in terms of self-reported knowledge, skills, and technology integration. Significant interaction effects show that teachers in the *tech* + *pbl* group had larger gains for self-reported knowledge and externally rated use of PBL. Three generalized estimating equation (GEE) models were fit to study the impact on students' ($N = 1{,}247$) self reported gains in behavior, knowledge, and attitudes. In the resulting models, students of *tech* + *pbl* teachers showed significant increases in gain scores for all

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three outcomes. By contrast, students of *tech-only* teachers showed improved gains only in attitudes.

Keywords Technology related teacher professional development · Problem-based learning · Generalized estimating equation

Introduction

The rapid growth in the creation and use of open-access *online learning resources and media* in education supports a transformative vision of education, one that can be more engaging and effective than current approaches. Online resources support new visualizations and modeling tools, are more affordable and interactive than textbooks, allow access to and manipulation of real-world datasets, and can be shared and adapted by communities of learners (McArthur and Zia 2008; Borgman et al. 2008; Patton and Roschelle 2008). In the hands of teachers, such resources can be tailored for students in increasingly diverse classrooms, and used in educative ways (Davis and Krajcik 2005). And while they can be used in a variety of educational contexts, online resources are particularly well suited to student centered inquiry oriented activities like problem-based learning (Gurell et al. 2010).

Yet teachers struggle when incorporating new resources, tools, and instructional approaches (Kramer et al. 2007; Mardis 2007; Recker et al. 2005) into their teaching. In particular, teachers vary in their technology integration knowledge, as well as in their ability to design pedagogically sound activities. As such, one documented approach for improving teachers' technology integration skills, knowledge, and attitudes is via teacher professional development (Borko 2004).

In this article, we describe and compare two technology-related teacher professional development (TTPD) designs. In both cases, the focal point was on helping teachers learn to design activities for students using online learning resources. In the first TTPD, teachers focused on integrating new technology skills with pedagogies already familiar to them. In the second, teachers paired technology skills with a new pedagogy, problem-based learning (PBL; Barrows 1986). In this way, the article (1) adds to the TTPD literature base, (2) examines TTPD impacts across the levels of teachers and students, and (3) employs statistical techniques to account for nested data, as follows.

First, in addition to being based on best practices in teacher professional development (e.g., Lawless and Pellegrino 2007; U.S. Department of Education 2010), the TTPD designs build substantially on prior iterations of our work (Robertshaw et al. 2010). In this way, by refining, replicating, evaluating, and scaling our TTPD approaches, we contribute to the growing body of literature on TTPD theory, research, and development (Roschelle et al. 2010).

Second, this research addresses the call to examine the links between teacher TTPD experiences, classroom practices, and resulting impacts on students (Lawless and Pellegrino 2007; Schlager et al. 2009; Wayne et al. 2008), especially with studies using larger samples, experimental approaches, and longitudinal scales (Lawless and Pellegrino 2007; Roschelle et al. 2010). As is described below, our study involved 36 mathematics and science junior high school teachers and 1,247 students over a sustained period of 3 months.

Third, the analysis of these data employed a Generalized Estimation Equation (GEE) (Liang and Zeger 1986) modeling technique to account for nested nature of the data. GEE models can adjust for an issue common to many educational research designs, in that students within a classroom share a more common experience than students across classrooms. Like prior research using Hierarchical Linear Modeling to examine student learning in problem-based learning environments (Finkelstein et al. 2011), our work contributes to a small, but growing body of literature using such models to examine the impacts of PBL-oriented teacher professional development on teacher practice as well as on students.

Review of literature

Prior research has documented that we know little about what teachers learn from engaging in professional development, and how it impacts student learning and engagement (Fishman et al. 2003; Wayne et al. 2008). Ideally, TTPD should change teachers' knowledge, beliefs, attitudes, and behaviors, because these correlate with classroom practice, thereby influencing student learning (Fishman et al. 2003).

Shulman (1986) proposed that effective teachers' knowledge consisted of *pedagogical knowledge* (PK), *content knowledge* (CK), as well as their important intersection, *pedagogical content knowledge* (PCK). More recent work posits additional important categories of teacher knowledge in a twenty first century world, called *technological knowledge* (TK), as well as their intersection, *technological pedagogical content knowledge* (TPCK) (Mishra and Koehler 2006; Niess 2005). While the TPCK construct does have its detractors (e.g., Maddux 2009), TPCK and its constituent constructs have recently undergone closer scrutiny (Archambault and Barnett 2010; Archambault and Crippen 2009; Graham et al. 2009). Based in part on those measurement studies, we focused on valid and reliable factors in order to characterize and refer to what teachers may know and learn as a result of engaging in TTPD. For the purposes of this work, those include teachers' self report of knowledge and use of technology (TK), designing effective lessons and customizing them for student needs (PCK), and using technology to create online lessons and utilize them in the classroom (TPCK). Although there is some debate about whether or not it is meaningful (or even possible) to assess TPCK elements in isolation (Angeli and Valanides 2009), there is general agreement that TPCK goes beyond its constituent parts in defining teacher practice through the meaningful integration of skills and knowledge in each area (Angeli and Valanides 2005; Koehler and Mishra 2008). For our purposes, TK, PK and CK are all important, and a separate measure for TPCK is needed over a simple sum of its parts.

To support the development of these skills and knowledge, the TTPD model used in the present research is design-oriented in that participating teachers learn to design instructional activities for their students. Proponents of a design-oriented approach argue that it enables teachers to learn new technology skills within an authentic instructional context. This helps them take ownership of new skills, making them more likely to integrate these into future teaching (Lawless and Pellegrino 2007). This perspective also fits with a more contemporary view of teaching as a kind of design task, in which teacher adaptation and use of materials is seen as a critical step in curriculum design (Brown and Edelsen 2003; Remillard 2005). Moreover, several interventions designed to increase TPCK focus on having teachers design curriculum (Angeli and Valanides 2009; Koehler and Mishra 2005a).

As noted above, the design of the current TTPD was informed by existing literature (Desimone 2009; Garet et al. 2001; Wayne et al. 2008) as well as our own previous iterations (Robertshaw et al. 2010). As explained below, both TTPD designs incorporate seven characteristics of effective TTPD distilled from a working group of practitioners and educational researchers (U.S. Department of Education 2010). These are: (1) relates to the teachers' content area, (2) is collaborative, (3) is consistent with the technology goals in the district, (4) allows for active engagement with content, (5) is tailored to different levels of teachers' knowledge, skills and interest, (6) is sustained, and (7) includes follow-up activities.

As described below, two TTPD designs were contrasted, one focusing solely on technology skills to design student activities using online resources, while the other coupled technology skills with learning to design *inquiry-oriented* activities for their students using online resources. The particular inquiry approach employed was *problem-based learning* (PBL), wherein students acquire knowledge through engaging with authentic problems (Barrows 1986; Barrows and Tamblyn 1980; Savery 2006). In PBL, problems are presented first and learners take on more autonomy, operating in small groups, and utilizing resources made available to them. Rather than lecture, the instructor facilitates by scaffolding learners' meta-cognition, coaching, and modeling problem-solving behavior (Hmelo-Silver and Barrows 2008). Content knowledge is acquired as needed in an effort to find a problem solution. Each problem cycle concludes with a reflection phase. PBL was selected as the TTPD approach with teachers in part because prior meta-analyses have shown effectiveness in both teacher education ($d = .64$), and when participants are engaged in design problems ($d = .74$) (Walker and Leary 2009).

Technology context

The technology context for the TTPD is the Instructional Architect (IA.usu.edu), a lightweight, free web-based tool, designed for authoring simple instructional activities using online learning resources from the National Science Digital Library (NSDL.org) and the Web (Recker 2006; Recker et al. 2005). The IA allows teachers search for, collect, annotate, store, and reuse online learning resources, then create instructional web pages, called IA projects. These IA projects can be kept private (private-view), or made available to only their students (student-view), or to anyone (public-view). Additionally, the IA allows for teachers to collaborate, by sharing projects with and copying projects from other IA users.

To create an IA project, teachers need to register for a free account. Once logged in, teachers can use the IA in several ways. The *'My Resources'* area allows teachers to search for and save online resources from the NSDL, from any resource with a valid Internet address, such as other web pages, pdf documents, or other IA projects. Finally, Web 2.0 technologies like RSS feeds and podcasts can be incorporated. All of these resources become the teachers' personal instructional collection. In the *'My Projects'* area, teachers can select online resources and annotate them with text to create IA projects. A webpage is generated systematically from what the teacher has selected which then can be used for instructional purposes. Finally, teachers can *'Publish'* IA projects using the private, student, or public options listed above.

Since 2005, the IA has over 6,100 registered users who have gathered over 70,000 online resources and created over 13,600 IA projects. Since August 2006, public projects have been viewed over 1.5 million times. Figure 1 shows an IA project created by a participant, which exhibits several elements of problem-based learning.

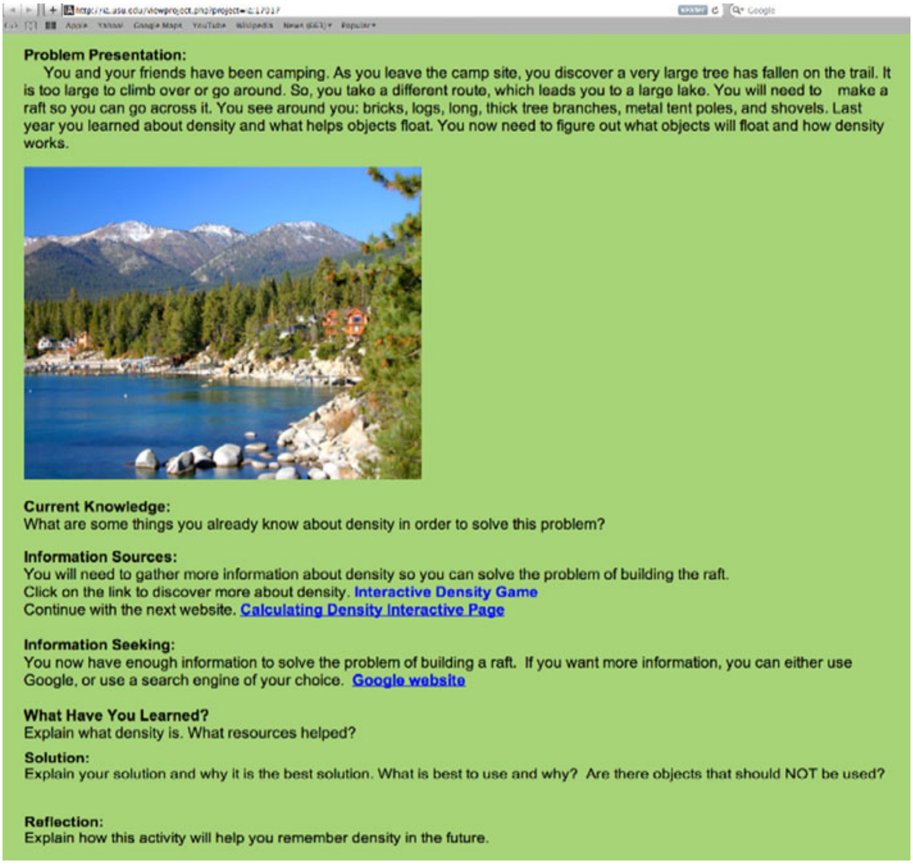

Fig. 1 A screenshot of a teacher-created IA project

Methods

This article reports results from a quasi-experimental study of TTPD impact that took place within a large suburban school district (75,000 students) in the U.S. West. The district proved an ideal testing ground in that all teachers were expected to teach to common math and science standards, had a rich culture of TTPD opportunities, and was engaged in concerted technology integration initiatives, including launching a laptop-only junior high school.

Table 1 shows the study's research questions, data sources, and analyses. As discussed below, research question 4 is more complex in that several candidate teacher and student variables were considered before their inclusion in the final model.

Professional development designs

Key activities for the two TTPD designs, *tech-only* and *tech + pbl*, as well as data collection points are shown in Fig. 2. In this section, we describe the TTPD designs following the four PD dimensions identified by Fishman et al. (2003): (1) content, (2) strategies, (3)

Table 1 Research questions, data sources, and analyses

Research question	Data sources	Analyses
1. What is the impact of the two TTPD designs on teachers' knowledge?	Teacher pre/post survey	Descriptives Factorial repeated measures ANOVA
2. What is the impact of the two TTPD designs on teachers' usage of the IA?	Web usage data	Descriptives
3. What is the impact of the two TTPD designs on design choices made by teachers in their IA projects?	PBL alignment score	Descriptives Factorial repeated measures ANOVA
4. What combination of teacher variables and student variables significantly predict student outcomes?	All of above, and student pre/post questionnaire	Descriptives GEE

site, and (4) media. The figure, (using number) and the associated discussion (using italics), also identifies how our designs align with the seven elements of effective TTPD designs previously described.

Content

Both TTPD designs focused on the following technology skills: (1) finding online resources, (2) designing activities for students using the IA, and (3) implementing these IA projects in the classroom. In the *tech-only* TTPD design, additional technology content included learning search strategies for online resources, methods for evaluating online resource quality, and advanced IA design skills. In the *tech + pbl* TTPD design, the additional focus was on learning to design inquiry-oriented activities, specifically PBL, using the IA. Both TPPD designs aimed to improve teachers' TK, PCK, and TPCK. In the case of the *tech-only* group, pedagogical knowledge was emergent and based on teachers incorporating instructional practices relevant to their particular classroom needs in order to design IA projects for their students. This emergent characteristic is a feature common to other implementations of learning by design (Koehler and Mishra 2005a). In the case of the *tech + pbl* group, the pedagogy consisted of problem-based learning. However, teachers in this group were asked to design IA projects incorporating PBL only if they felt it aligned with their self-selected design problem, student needs, and their own educational philosophy. In addition, teachers in both groups selected the design problems for their classroom, assuring a strong connection to their own *content area* and promoting *active engagement*.

Strategies and site

The two TTPD designs were implemented as a series of three face-to-face workshops with in-between classroom implementation and *follow-up activities*, *sustained* over 3 months. Each design had a different facilitator, both of whom helped develop the workshops and both of whom are also authors. Following design-oriented approaches in technology integration professional development (Lawless and Pellegrino 2007), the teachers *actively engaged* with authentic and complex problems in their own teaching, designed solutions, and reflected with their peers on classroom implementation *collaboratively* discussing

Tech-only TTPD	*Tech+pbl* TTPD	Data Collected
Workshop 1: 3 hours (6)		
1. Take pre-survey 2. View example IA projects 3. Select a teaching need (1; 4) 4. Intro to online resources 5. Intro to IA: Walk through project creation 6. Discuss selection of quality of online resources (2) 7. Individuals design IA project(s) 8. Review IA functionality (3; 4)	1. Take pre-survey 2. View example PBL IA projects 3. Select a teaching need (1; 4) 4. Intro to online resources 5. Intro to IA: Walk through project creation 6. Individuals design IA projects 7. Review IA functionality (3; 4) 8. Large and small-group discussion on inquiry learning and designing inquiry problems (2)	• Pre-survey
Classroom Implementation #1 (7)		
1. Design IA project(s) 2. Classroom implementation of IA project 3. Administer student questionnaire 4. Write reflection paper on barriers and successes in classroom implementation	1. Design IA project(s) 2. Classroom implementation of IA project 3. Administer student questionnaire 4. Write reflection paper on barriers and successes on classroom implementation 5. Devise potential inquiry problems suitable to context	• Student pre/post questionnaire • PBL alignment of IA project • Web usage
Workshop 2: 3 hours (6)		
1. Small then large group discussion of implementation experiences (2) 2. Review use of the IA, including advanced tech features (3; 4) 3. Small group discussion on existing and potential new IA projects (1) 4. Design a new IA learning activity 5. Large group discussion on IA and project design (2)	1. Small then large group discussion of implementation experiences (2) 2. Review use of the IA (3; 4) 3. Engage in inquiry-oriented activity using "World of Goo" (2) 4. Large group discussion of inquiry and PBL (2) 5. Design own PBL learning activity 6. Share ideas in small then large groups (2)	
Classroom Implementation #2 (7)		
1. Design new IA project(s) with students 2. Classroom implementation of IA project 3. Administer student questionnaire 4. Write reflection paper on barriers and successes in classroom implementation	1. Design and implement new IA project(s) with students, encouraging use of PBL. 2. Classroom implementation of IA project 3. Administer student questionnaire 4. Write reflection paper on barriers and successes on classroom implementation	• Student pre/post questionnaire • PBL alignment of IA Project • Web usage
Workshop 3: 3 hours (6)		
1. Small then large group discussion of implementation experiences (2) 2. Review technical use of the IA, including advanced features 3. Take post survey	1. Individual reflection on IA project and PBL implementation 2. Small then large group discussion of IA project and PBL implementation (2) 3. Review technical use of the IA 4. Take post survey	• Post survey

Fig. 2 Key activities for the two TTPD designs and data collection points. Numbers show the seven characteristics of effective TTPD design: 1 = relates to content area; 2 = collaborative; 3 = consistent with district goals; 4 = active engagement; 5 = tailored to different levels of knowledge; 6 = sustained with three contacts over 3 months with in-between activities; 7 = follow-up activities. Tailoring and district goals are discussed below

barriers, ways to overcome barriers, best practices, and potential uses of the technology. Both workshops took place in the same district computer lab.

Media

Each teacher had hands-on access to the Internet, a TTPD curriculum guide, the IA (described above), search engines, and online resources. In conjunction with an ongoing *district technology integration effort,* teachers became media producers as well as media consumers, publishing their finished IA projects on a district website.

Participants

A total of 51 mathematics and science teachers (grades 7–9) from 15 junior high schools in one school district initially signed up to participate. Participating teachers were assigned (based on scheduling preference but blind to condition) to one of two TTPD designs. Eighteen participants (71%) from each TTPD group completed all requirements and received a stipend and one university course credit. Table 2 summarizes participating teacher characteristics. 1,247 students (age 12–15) in these teachers' classes completed pre/post questionnaires.

Data sources

Although several different measures are utilized, two of them rely on self-report data from teachers and from students. Past research has shown congruence between student-self report and performance based measures of problem solving (Reeves and Laffey 1999). Teacher self-report data has been used in several prior research efforts specific to technology integration (Brush 2003; Dick et al. 2001; Fletcher 2006). Self-report does carry the risk of self-report bias (Kopcha and Sullivan 2007) but represents a feasible means of data collection especially for the multi-level context of this research.

Teacher survey

We collected pre/post data on teachers' experiences in the TTPD through an online survey administered at the before and after the TTPD. The survey consisted of 18 Likert scale items addressing teacher self-reported knowledge aligned to sub-scales for TK, PCK, TPCK, and PBL. Likert scales ranged from 0 ("strongly disagree") to 4 ("strongly agree"). Items were drawn from several sources (Becker 2000; Archambault and Barnett 2010; Archambault and Crippen 2009), as well as our previous research (Robertshaw et al. 2010). We also examined knowledge of search strategies, as well as teachers' future intentions to use PBL. Example items include "I can use technology to adapt my lessons to the needs of my students" (TPCK), "I am confident I can help students make connections between various concepts in a curriculum" (PCK), "I can troubleshoot technical problems associated with hardware" (TK), and "I know how to teach using problem-based learning" (PBL).

Responses on items for each sub-scale were summed. A *t*-test of pretest scores showed no significant differences between groups ($p > .05$). Overall survey reliability was high ($\alpha = .88$) and the Cronbach's alpha for each sub-scale was also high, ranging from .78 to .97. All teachers except one completed the post-survey. For this teacher, missing data were imputed.

Table 2 Teacher demographics

Teacher demographics	Tech-only TTPD	Tech + pbl TTPD
N Teachers (% Female)	18 (72%)	18 (61%)
Mean (SD) # of years in current position	9.0 (6.38)	12.8 (9.35)
% Math teachers	44%	22%
% Science teachers	56%	78%

Web usage data

The IA system automatically collects data about teachers' use of the IA (Khoo et al. 2008), and was used as a proxy for behavior. Data for each teacher included number of logins, IA projects created, online resources used, and student visits to each IA project.

PBL alignment of IA projects

Using items based previous research (Walker and Shelton 2008; Walker et al. 2011), we refined a rubric to score alignment with PBL (see "Appendix A"). The rubric consisted of 11 elements in four categories (Authentic Problem, Learning Processes, Facilitator, and Group Work). While each element in isolation (for example group work) does not itself constitute PBL instruction, it is closer to PBL than an intervention that does not involve group work. PBL is a term that "can have many different meanings depending on the design of the educational method employed" (Barrows 1986, p. 481). The rubric borrows heavily from that perspective and the associated assumption that designs that more closely adhere to the central tenets of PBL will result in improved student outcomes. Finally, by separating constructs like group work from authentic problems, the rubric avoids double-barreled features while maintaining sensitivity to variations between teacher designs. Note that Barrows later (1996) lamented that the wide variation in PBL interventions led to a lack of precision about what PBL means. We argue that PBL informed our TTPD design for teachers and that we attempt to assess the degree to which teachers implemented PBL in their classrooms. We would only label a handful of their implementations as PBL.

Three raters, randomly selected from a pool of five and blind to TTPD condition, independently scored teachers' IA projects. Each element's score ranged from 0 to 2 (0 = "not present"; 2 = "present"), for a maximum possible score of 22 points. For reliability, overall average one-way random effects intra-class correlation (ICC) (Shrout and Fleiss 1979) was .86. Interpreted like a kappa statistic (Fleiss and Cohen 1973), this particular score indicates almost perfect agreement (Sim and Wright 2005).

Student questionnaire

Teachers in the study administered paper-based pre/post questionnaires to their students before and after each of the two classroom implementations of IA projects. Since teachers taught different courses, an achievement test of student knowledge was not feasible. Instead, the student questionnaire contained seven self-report Likert scale items, with scales ranging from 1 = "strongly disagree" to 5 = "strongly agree." Two items addressed student behavior (e.g., "I will spend time learning about this topic on my own"; reliability $\alpha = .78$), three addressed knowledge (e.g., "I know enough to teach my friends about this topic", reliability $\alpha = .81$), and two addressed attitude (e.g., "After this activity, I like this topic very much", reliability $\alpha = .77$).

Teachers selected one of their classes in which to administer the student questionnaire. Responses on items for each sub-scale were summed. Enrollments at the class level are unknown but based on district averages we estimate a 67.7% student response rate. As with each of the sub-scales, overall questionnaire reliability was high ($\alpha = .79$). For the purposes of validity, a confirmatory factor analysis showed three total factors. All were precisely aligned to the sub-scales as planned. One loading was at .68, the rest were at or above .85. Given the combination of a large sample size ($N = 1{,}247$), and strength of factor loadings (Stevens 1999) these data appear to be valid measures of student self-reports for behavior, knowledge, and attitude.

Results

Results are organized by research questions below. All inferential statistical tests used an alpha level of .05. Where appropriate, effect sizes are calculated, including Cohen's *d* (1988), for mean differences and eta-squared (η^2) (Ferguson 2009) for ANOVA.

Research question #1: impact on teachers

A two-way factorial ANOVA with repeated measures was conducted to determine whether there was a statistical difference between the two different TTPD designs on each of the five sub-scale scores. The independent variables were a between-subjects variable with two levels (*tech-only, tech + pbl*), and a within-subject variable, repeated measures of pre-survey and post-survey scores on each of the sub-scales.

Table 3 shows results for each of the five subscales. The analyses revealed significant main effects of pre/post-survey on *all* sub-scales, showing that teachers' scores increased. Following Ferguson's (2009) guidelines, there were *small* effect sizes for PCK and PBL subscale scores, *moderate* effect sizes for the TPCK and TK sub-scale scores, and *strong* effect sizes for the Search sub-scale scores.

The analyses also revealed a significant TTPD design × PBL sub-scale interaction, $F(1, 34) = 4.79$, $p < .05$, $\eta^2 = .05$. As shown in Fig. 3, the interaction indicated that the *tech + pbl* teachers had larger gains in self-reported PBL knowledge than the *tech-only* teachers. While both groups experienced gains, they did so at much different rates. In addition, the means on the post-survey for the *tech + pbl* teachers were closer to the top of the scale. There were no other interaction effects observed.

To further explore the differences between the two TTPD designs, descriptive statistics for each TTPD design and effect sizes of group gains are shown below in Table 4. As can be seen, the *tech + pbl* group is higher on all effect sizes except on TK. The latter construct, of course, was emphasized for the *tech-only* teachers. Differences in gains between groups (including TK) were fairly small, with the exception of PBL where *tech-only* gains were medium in size and *tech + pbl* gains were large.

Finally, a post-test only question asked teachers to indicate the degree they would use PBL in the future. An independent-sample *t*-test comparing teachers' responses showed a significant difference between the scores in the two TTPD designs, $t(34) = -2.54$,

Table 3 Descriptives and main effects of the factorial repeated measures ANOVA

Sub-scale	Pre-survey		Post-survey		$F(1,34)$	η^2
	M	SD	*M*	SD		
PCK (0–16)	11.58	2.66	12.98	2.43	6.58*	.16
TPCK (0–24)	12.97	4.54	19.09	2.99	50.71**	.60
PBL (0–8)	4.83	1.84	5.94	1.72	10.12*	.22
TK (0–12)	5.22	3.94	7.35	2.74	17.55**	.34
Search (0–12)	6.92	2.47	10.10	1.91	60.08**	.64

* $p < .05$, ** $p < .01$. Eta squared cut-offs: small = .04, moderate = .25, strong = .64

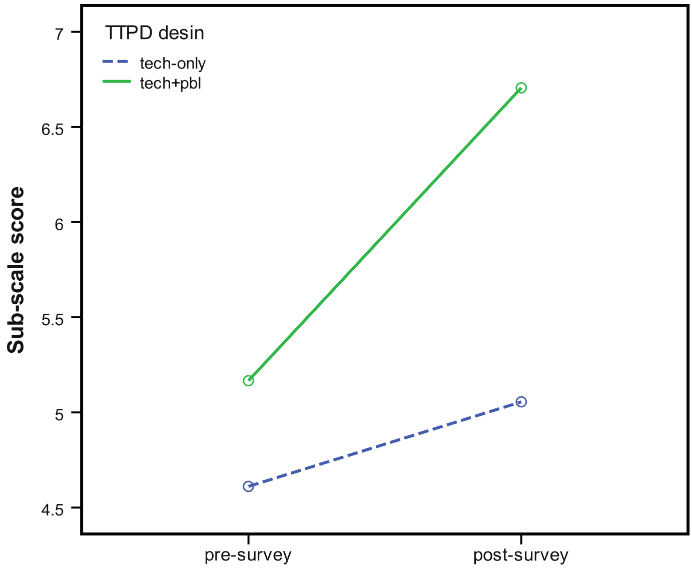

Fig. 3 Estimated marginal means of teacher PBL knowledge for each TTPD design

Table 4 Teacher knowledge for PCK, TPCK, PBL, TK, and search sub-scales

	Pre-survey		Post-survey		
	M	SD	*M*	SD	*d*
Tech-only TTPD (range per sub-scale)					
PCK (0–16)	11.89	2.14	12.78	1.35	.48
TPCK (0–24)	13.22	4.89	19.00	2.63	1.45
PBL (0–8)	4.61	1.75	5.17	1.72	.32
TK (0–12)	4.44	4.02	6.94	3.02	.69
Search (0–12)	6.50	2.62	9.50	1.89	1.32
Use PBL in the future? (0–4)	N/A	N/A	2.61	.98	N/A
Tech + pbl TTPD (range per sub-scale)					
PCK (0–16)	11.28	3.12	13.18	3.20	.60
TPCK (0–24)	12.72	4.30	19.18	3.38	1.63
PBL (0–8)	5.06	1.96	6.71	1.36	.96
TK (0–12)	6.00	3.82	7.76	2.44	.54
Search (0–12)	7.33	2.30	10.71	1.77	1.61
Use PBL in the future? (0–4)	N/A	N/A	3.35	.76	N/A

Possible minimum is 0

$p < .05$, indicating a greater intention by teachers in the *tech + pbl* group. An effect size comparison of these means suggests a substantial difference between the groups ($d = .84$).

Research question #2: impact on IA usage

One teacher's usage data in the *tech-only* group was an outlier. Rather than lose her completely, her usage data were trimmed to three SD over the mean (Lipsey and Wilson

2001). As seen in Table 5, overall usage is high. Teachers on average each logged in about ten times more ($M = 30.11$) than the three logins required as part of the face-to-face workshop contacts. Teachers averaged more than 800 student visits to their projects. In terms of long-term impact, over half of the teachers logged into the IA 6 months after the conclusion of the TTPD. In sum, both TTPD designs appeared to have high usage by both teachers and students.

Research question #3: impact on teacher designs

This research question examined teachers' IA projects in terms of their alignment with PBL. The median rating from three raters was used as the IA project's PBL alignment score. Given the use of three raters and the proximity of rating decisions, this is a reliable approach for arriving at an operational score (Johnson et al. 2010). Results discussed below report the mean of these median scores for a particular group or design time point.

A two-way factorial ANOVA with repeated measures was conducted to determine whether there was a statistical difference between the two different TTPD designs in terms of the PBL alignment scores. The independent variables were a between-subjects variable with two levels (*tech-only, tech + pbl*), and a within-subject variable, repeated measures of PBL alignment scores from the first and second IA project design (see Table 6). The analysis revealed a significant main effect of design time, showing that PBL alignment scores increased between teachers' first and second design.

The analysis also revealed a significant TTPD design × PBL alignment score interaction, $F(1,34) = 4.55$, $p < .05$, $\eta^2 = .10$. As shown in Fig. 4 and Table 7, the interaction indicated that teachers in the *tech + pbl* design had significantly larger gains in PBL alignment scores than the *tech-only* teachers. Recall that *tech + pbl* teachers also had significantly larger gains in self-reported PBL knowledge than the *tech-only* teachers. These two results provide converging evidence about the positive impact of the *tech + pbl* TTPD design on teachers' knowledge and design skills.

Note, however, that these scores are likely an under-estimate of what happened in the classroom. Teachers may have asked students to work in groups, as one example, even though the IA project did not make that clear. In addition, the means for all PBL scores were quite low, which may be the result of this underestimation, an overly strict measure, or may suggest that the PBL portion of the TTPD was not effective.

Research question #4: predicting student outcomes

We analyzed student data using the Generalized Estimating Equation (GEE) (Liang and Zeger 1986) to account for the nested nature of the research design. While other models,

Table 5 IA usage data for all teachers (measured 9 months after start of TTPD)

	M	SD	Max
# of teacher logins to the IA	30.11	14.59	80
# of IA projects created	8.64	5.42	30
# of collected online resources used	32.14	26.52	138
# of collected resources used per IA project	3.80	2.00	11.83
# of student visits to the IA projects	859.92	760.67	2,766

Table 6 Descriptives and main effect of the factorial repeated measures ANOVA

	IA project design #1			IA project design #2			$F(1,34)$	η^2
	M	SD	Max	*M*	SD	Max		
PBL alignment score	2.53	2.10	9	4.11	4.29	17	5.27	.12

Possible values range from 0 = low to 22 = high, * $p < .05$ ** $p < .01$

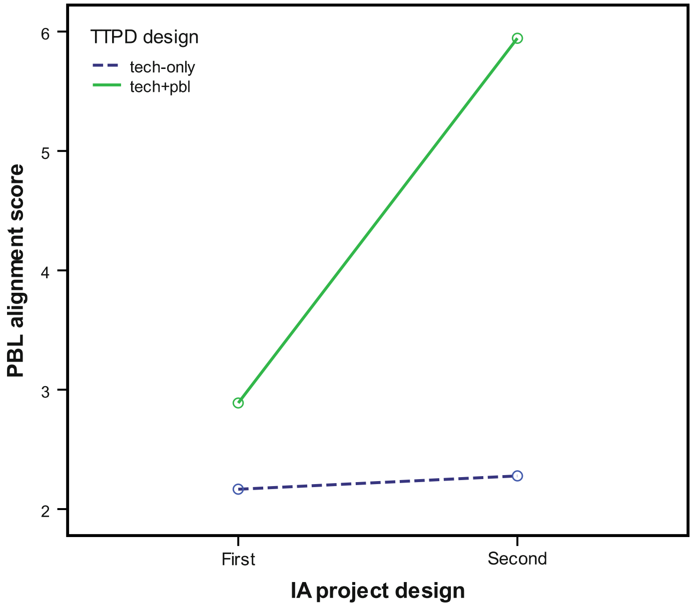

Fig. 4 Estimated marginal means of teachers' PBL alignment scores for IA projects designed by each group at each time point

Table 7 IA project PBL alignment scores for each TTPD design

	Mean	SD	Max
Tech-only TTPD ($N = 18$)			
PBL alignment score in first design of IA project	2.17	1.95	9
PBL alignment score in second design of IA project	2.28	2.14	10
Tech + pbl TTPD ($N = 18$)			
PBL alignment score in first design of IA project	2.89	2.25	9
PBL alignment score in second design of IA project	5.94	5.12	17

Possible values range from 0 = low to 22 = high

such as Hierarchical Linear Modeling (HLM) are also appropriate, GEE is well suited for this purpose in that it handles data which violates distributional assumptions and is robust for a variety of data types. Moreover, GEE provides population-averaged estimates, while HLM provides the subject-specific estimates of the mixed-effects regression models (Hedecker and Gibbons 2006). In the current study, we are more interested in predicting the population-averaged outcomes, rather than classroom level effects.

Model fitting was done using STATA 11 statistical software. To select the best working correlation structure (Horton and Lipsitz 1999; Ballinger 2004) and to aid in selection of predictors for the GEE model, the QIC score was calculated for each model. The QIC score is commonly used as a statistical basis for comparing model fit. In general, the smaller the value, the better the fit of the predictor combinations (Pan 2001; Cui 2007). Three variables (TTPD design, classroom implementation, and PBL alignment score) were included irrespective of QIC because they were considered important to the study. To statistically test whether each coefficient (estimated in the tables that follow) was substantially greater than zero, we followed the recommendations of Rotnitzky and Jewell (1990) in relying on the Wald Chi-square statistic. A total of three separate GEE models were selected, to reflect the three student level dependent variables: behavior, knowledge, and attitudes. Each variable reflects a gain score on a pre-post measure administered just before and just after a teacher's classroom implementation of the IA project design at two different time points: one after the first TTPD workshop, and one after the second. Table 8 shows the descriptive statistics for each subscale, at each time point, for both TTPD designs.

All three models used teacher as the cluster variable and included both teacher level and student level predictors. Both the estimate and the *p* value are important to consider when examining parameters for the model. The estimate indicates the level of contribution each independent variable has to the model, and the *p* value indicates if it is statistically significant.

Student self-reported behavior gains

For student behavior gains, there were four statistically significant independent variables (see Table 9). The larger factors were TTPD design and classroom implementation. While they might be statistically significant, the positive relationship with the number of teacher IA logins (e.g., the more logins the greater the gain in student behavior) and the inverse

Table 8 Gain scores for students' self-reported behavior, knowledge, and attitudes

	Implementation 1			Implementation 2			Total		
	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*
Student behavior gains									
Tech-only TTPD	1.42	2.25	264	1.58	2.10	280	1.50	2.17	544
Tech + pbl TTPD	.96	2.02	345	1.30	2.00	358	1.13	2.01	703
Total	1.16	2.13	609	1.43	2.05	638	1.30	2.09	1,247
Student knowledge gains									
Tech-only TTPD	.75	1.81	264	1.46	1.96	280	1.11	1.92	544
Tech + pbl TTPD	.95	1.93	345	1.36	2.05	358	1.16	2.00	703
Total	.86	1.88	609	1.40	2.01	638	1.14	1.97	1,247
Student attitude gains									
Tech-only TTPD	−.15	1.63	264	.29	1.48	280	.07	1.57	544
Tech + pbl TTPD	−.19	1.54	345	.11	1.61	358	−.04	1.58	703
Total	−.18	1.58	609	.19	1.56	638	.01	1.58	1,247

Student knowledge and attitudes subscales range from −8 to 8. The student behavior subscale ranges from −12 to 12

Table 9 Estimated coefficients, SEs and *p* values: the GEE model for student behavior gains

	Final model		
	Estimate	SE	*p* value
Intercept	2.08	.77	.01
TTPD design	−.61	.14	.01
Classroom implementation	.25	.13	.05
PBL alignment score	.02	.01	.21
Teacher PCK	−.01	.03	.08
Teacher TPCK	−.03	.03	.23
Teacher PBL knowledge	.06	.04	.07
Teacher TK	.03	.02	.21
Teacher Search	.04	.04	.37
# of teacher IA logins	.02	.01	.01
# of IA projects created	−.05	.02	.01
# of collected resources used	−.05	.03	.08
School	.03	.02	.26
Teaching experiences	−.01	.01	.32
QIC score	5268.06		

relationship with the number of IA projects created (e.g., the fewer the projects the greater the gain in student behavior) did not make an important contribution to the model.

Since the TTPD design represents categorical data, the coefficient is best interpreted through post-estimation. Post-estimation of TTPD design (see Table 10) initially suggests that students of *tech-only* teachers consistently showed greater behavior gains. However, when looking at changes over time, the picture changes.

For the classroom implementation, the post-estimation analysis (see Table 11) showed no statistically significant change in student gain scores from the first to second classroom implementation for students of *tech-only* teachers. The same was not true for students of *tech* + *pbl* teachers who did show improved behavior gain scores at the second classroom implementation. Taken in combination, this suggests pre-existing differences favoring students of *tech-only* teachers. Although students of *tech* + *pbl* teachers showed gains, they were not at a level that overcame those prior differences.

Student self-reported knowledge gains

For student's self reported knowledge gains (see Table 12), the single largest and only statistically significant contributor to the model was the classroom implementation. This suggests an improvement from the first to the second classroom implementations of IA projects.

Post-estimation (see Table 13) suggests that the student knowledge gains were about the same for the *tech-only* group at both time points. For the *tech* + *pbl* group, the gains were similar to the *tech-only* group at the first classroom implementation but significantly larger at the second. The significant classroom implementation coefficient is based on group differences at both times.

Table 10 Post-estimation of the student behavior gains between TTPD designs

TTPD design	Final model		
	LS means	95% CI	*Z*
Classroom implementation 1 (*N* = 609)			
Tech-only TTPD (*N* = 264)	1.39	(1.16, 1.61)	2.84**
Tech + pbl TTPD (*N* = 345)	.99	(.83, 1.15)	
Classroom implementation 2 (*N* = 638)			
Tech-only TTPD (*N* = 280)	1.62	(1.38, 1.87)	2.37*
Tech + pbl TTPD (*N* = 358)	1.28	(1.12, 1.43)	
Total (*N* = 1,247)			
Tech-only TTPD (*N* = 544)	1.51	(1.31, 1.71)	3.25**
Tech + pbl TTPD (*N* = 703)	1.13	(1.03, 1.24)	

* $p < .05$, ** $p < .01$

Table 11 Post-estimation of the student behavior gains between classroom implementations

Classroom implementation	Final model		
	LS means	95% CI	*Z*
Tech-only TTPD (*N* = 544)			
Classroom implementation 1 (*N* = 264)	1.39	(1.16, 1.61)	1.35NS
Classroom implementation 2 (*N* = 280)	1.62	(1.38, 1.87)	
Tech + pbl TTPD (*N* = 703)			
Classroom implementation 1 (*N* = 345)	.99	(.83, 1.15)	2.26*
Classroom implementation 2 (*N* = 358)	1.28	(1.12, 1.43)	
Total (*N* = 1,247)			
Classroom implementation 1 (*N* = 609)	1.16	(1.01, 1.32)	2.39*
Classroom implementation 2 (*N* = 638)	1.43	(1.27, 1.59)	

* $p < .05$, ** $p < .01$

Table 12 Estimated coefficients, SEs and *p* values: the GEE model for student knowledge gains

	Final model		
	Estimate	SE	*p* value
Intercept	−.79	1.09	.47
TTPD design	.01	.32	.99
Classroom implementation	.48	.18	.01
PBL alignment score	.06	.05	.19
# of teacher IA logins	.01	.01	.08
# of student visits to the IA projects	−.01	.01	.18
Teaching experiences	−.02	.02	.39
Grade	.12	.13	.35
QIC score	4675.04		

Student self-reported attitude gains

Similar results are found in the model for student attitudes (see Table 14). Once again, classroom implementation was the key predictor variable.

Post-estimation (see Table 15), however, suggests a slightly different picture. Unlike behavior and knowledge gains, for student attitudes, gains occurred from the first to the second classroom implementation across both TTPD designs.

Discussion and conclusion

In this article, we traced a path between two TTPD designs, teachers' experiences, usage of the IA, self-reported knowledge and externally rated usage of PBL, and corresponding impacts on student's perceptions of their own engagement and learning. As noted above, the work reported in the article built substantially on our prior efforts by improving TTPD materials and research instruments. The research design was also more rigorous and used a larger teacher and student sample. In this way, the current study contributes to TTPD theory, research, and development, as well as evaluation and scaling approaches.

The first focus of the study was to investigate the overall impact of the TTPD designs on teachers' knowledge and behaviors. Results showed that teachers in both TTPD designs benefited, with large self-reported gains in the five knowledge constructs measured. These results support the literature arguing that professional development can have positive influences on teacher's knowledge and skills (Borko 2004). Moreover, teachers' technological knowledge as well as integrated forms of pedagogical content knowledge and technological-pedagogical content knowledge also showed gains. The different rates in the gains lend support for claims that it is important to measure TPCK as a separate construct from its constituent parts (Angeli and Valanides 2005; Koehler and Mishra 2008). Teacher TPCK gains (see Table 4) were dramatically larger than TK and PCK gains in both TTPD designs. Usage of the IA by both teachers and students was high, aligning with results from our prior work (Walker et al. 2011). Specifically, teachers in both TTPD designs made use of the IA and online resources, with more than half logging in 6 months after the conclusion of their TTPD.

Table 13 Post-estimation of the student knowledge gains between classroom implementations

Classroom implementation	Final model		
	LS means	95% CI	Z
Tech-only TTPD ($N = 544$)			
Classroom implementation 1 ($N = 264$)	.86	(.44, 1.29)	1.67NS
Classroom implementation 2 ($N = 280$)	1.35	(.96, 1.75)	
Tech + pbl TTPD ($N = 703$)			
Classroom implementation 1 ($N = 345$)	.86	(.48, 1.24)	2.25*
Classroom implementation 2 ($N = 358$)	1.44	(1.11, 1.78)	
Total ($N = 1{,}247$)			
Classroom implementation 1 ($N = 609$)	.86	(.56,1.16)	2.56*
Classroom implementation 2 ($N = 638$)	1.40	(1.11, 1.69)	

* $p < .05$, ** $p < .01$

Table 14 Estimated coefficients, SEs and *p* values: the GEE model for student attitude gains

	Final model		
	Estimate	SE	*p* value
Intercept	.19	.64	.77
TTPD design	−.20	.15	.18
Classroom implementation	.32	.13	.01
PBL alignment score	.03	.03	.33
Teacher PCK	−.03	.02	.19
# of IA projects created	.02	.01	.12
# of Student visits to the IA projects	−.01	.01	.31
School	−.02	.02	.19
QIC score	3039.32		

Table 15 Post-estimation of the student attitude gains between classroom implementations

Classroom implementation	Final model		
	LS Means	95% CI	*Z*
Tech-only TTPD ($N = 544$)			
Classroom implementation 1 ($N = 264$)	−.11	(−.33, .12)	3.03**
Classroom implementation 2 ($N = 280$)	.24	(.05, .44)	
Tech + pbl TTPD ($N = 703$)			
Classroom implementation 1 ($N = 345$)	−.23	(−.41, −.05)	2.57*
Classroom implementation 2 ($N = 358$)	.15	(−.08, .37)	
Total ($N = 1{,}247$)			
Classroom implementation 1 ($N = 609$)	−.18	(−.33, −.02)	3.07**
Classroom implementation 2 ($N = 638$)	.19	(.02, .36)	

* $p < .05$, ** $p < .01$

Comparison between TTPD designs was the second focus of the study, in particular teachers' self-reported knowledge and externally rated use of PBL. Results revealed interaction effects, showing that *tech + pbl* teachers had larger gains in PBL knowledge than the *tech-only* teachers. They also showed larger gains in their use of PBL elements than the *tech-only* teachers. This suggests two important things. First, teachers' self-reported knowledge of PBL appears to coincide with their observed usage, at least within this context. Second, the *tech + pbl* TTPD design effectively promoted knowledge gains and increased use of PBL. These shifts are non-trivial since they require a shift in teaching practices to be more student-centered. Despite any institutional barriers and despite existing beliefs of the teachers themselves (Ertmer 2005), teachers expressed more knowledge of and were willing to utilize more elements of a student-centered approach like PBL.

The third focus of the study was to link teacher practice with student learning and engagement, while accounting for variations due to individual teachers. When combined, students of teachers in both TTPD designs had better self-reported gains across all outcomes after the second classroom implementation. However, this was not the case for student level gains when students were separated into TTPD groups. Only the students of *tech + pbl* teachers showed statistically significant gains across all three student outcomes. Students of *tech-only* teachers showed improved gains exclusively on attitudes. It appears that a participant driven exploration of pedagogies aligned to teacher and classroom needs, as advocated by learning by design (Koehler and Mishra 2005b), may not be as effective as exploring a specific pedagogy (in this case, PBL). This does not challenge TPCK on a theoretical basis since the recommendation is to integrate pedagogy with technology and content. The finding, however, is at odds with many of the TPCK based interventions, and learning by design in particular.

Limitations

Limitations of the study include threats to internal validity through the use of intact groups randomly assigned to TTPD condition and the relatively small teacher sample. Other threats include differences in the skill of the workshop leaders and that the workshops were developed and led by study authors. In addition, teachers selected the class to which they administered the student questionnaire, teachers from different groups may have worked collaboratively during and after workshops, and teachers and students may have provided socially desirable responses on the questionnaires. Teachers, in particular, may have provided socially desirable responses since they volunteered to participate. In the case of students, the anonymity of the surveys should help minimize the threat and for teachers, at least on the PBL knowledge items, the parallel PBL alignment scores provide some support for the veracity of their responses. Finally, there may have been pre-existing differences between treatment groups, such as prior exposure to PBL.

Implications for Future work

As discussed above, the means for the PBL alignment scores were low. Future work is needed to clarify if this is due to a lack of instrument sensitivity or to the difficulty teachers experienced in designing PBL activities. A focus on clarifying how teachers implement PBL in their classrooms as well as how this impacts student learning outcomes could help in confirming the sensitivity of the PBL rubric. Assuming a better range can be observed, future research might be better positioned to find a predictive link between PBL alignment and student outcomes. The data in this study with a nested structure could also be analyzed with a multilevel modeling technique that uses different estimation algorithms. Finally, future work might explore alternative pedagogical frameworks to PBL, determining if presenting PBL to teachers is an important factor in student outcomes, or if other specific pedagogies can show similar impacts. Practitioners engaged in TTPD might consider integrating specific pedagogical interventions alongside technology skills training but caution and replication work is needed. They should, with confidence, consider interventions that are sustained over time. The sole consistent predictor of student gains was having the second implementation of an IA project, a recommendation already well established in the literature.

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Appendix A

Criteria	Not present (0)	Emerging (1)	Present (2)
Authentic problem			
Cross-disciplinary	Content draws from a single discipline (e.g., statistics)	Content draws from two closely related disciplines (e.g., statistics and algebra)	Content draws from a diverse set of disciplines, reflecting the kind of complexity found in real life settings (e.g., statistics, and rhetoric)
Ill-structured	Learners are provided with clear directions	Learners are provided with parameters but need to make some decisions about how to proceed	Learners need to act within parameters and are faced with competing constraints, forcing a "satisficing" solution (e.g., students are asked to pick food that is cheap as well as healthy)
Real life	No ties to real life practice	Attempted ties to real life practice. Something done by professionals, or authentic for students	Learning is clearly tied to real life practice. For example, the problem is phrased in the first person for students, they are given artifacts associated with the problem
Begins with a problem	No contextual problem is presented to learners	Learners are asked to solve a contextual problem (content first)	Learners are asked to solve a contextual problem (problem first then content)
Learning processes			
Learning goals	Students play no role in deciding what to learn	Students have limited choice about what to learn	Students choose the majority of what they learn
Resource utilization	Learners are not prompted to locate/use any resources	Learners are asked to search for resources or utilize provided resources	Learners are asked to search for resources or utilize provided resources. Additionally they are encouraged to pay attention to the quality of resources they find or use
Reflection	Learners are not asked to reflect	Learners are asked to discuss what they have found or judge the merits of their own actions or the actions of their peers	Learners are asked to discuss what they found and judge the merits of their own actions or the actions of their peer
Facilitator			
Metacognition	Unclear exactly what facilitators do during the activity	As part of the activity, facilitators engage in some meta-cognitive prompts	As part of the activity, facilitators focus their efforts on providing meta-cognitive prompts (e.g., How helpful is your current line of reasoning? What do you need to do next? Can you summarize our discussion to this point?)

Appendix A continued

Criteria	Not present (0)	Emerging (1)	Present (2)
Information source	Facilitators are primary source of info. This either comes directly from the instructor or a mandated set of materials	Information comes partly from facilitators and is partly found by learners	Information is found primarily by learners. Sources include searching, or distilling relevant information from a larger set of provided materials
Group work			
Learners interact in groups	The learning experience is done individually	Parts of the learning done individually parts are done as a group	The majority of the learning is done in groups

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