Internet and Higher Education 26 (2015) 33–41

Contents lists available at ScienceDirect

Internet and Higher Education

Mobile augmented-reality artifact creation as a component of mobile computer-supported collaborative learning

Fengfeng Ke [a,*], Yu-Chang Hsu [b]

[a] Department of Educational Psychology and Learning Systems, Florida State University, Tallahassee, FL, 32306-4453, United States
[b] Department of Educational Technology, Boise State University, Boise, ID, 83725-1747, United States

ARTICLE INFO

Article history:
Accepted 14 April 2015
Available online 16 April 2015

Keywords:
Mobile computer-assisted collaborative learning
Augmented reality
Technological pedagogical content knowledge
Learning by making

ABSTRACT

This exploratory study examined the effectiveness of smartphone-based, AR artifact creation and other mobile collaborative learning activities in reinforcing the technological pedagogical content knowledge (TPACK) of pre-service teachers. Adopting a mixed-method research design, the study indicated that mobile AR artifact creation with peer discussion tended to better promote the componential competencies of technological pedagogical knowledge (TPK) and the integrative development of technological pedagogical content knowledge (TPACK), whereas mobile media artifact viewing with peer discussion seemed to better support the content knowledge (CK) development.

1. Introduction

Similar to the vast potential of leveraging mobile technologies for learning with augmented reality, there is great opportunity of applying mobile technologies in the context of collaborative learning (Hsu & Ching, 2013; Laurillard, 2009; Stahl, Koschmann, & Suthers, 2006). Based on Vygotsky's sociocultural theory (Vygotsky, 1978), social environment is critical in individuals' development and learning. By integrating the emerging mobile applications into a mobile-friendly web conferencing platform, it is possible to structure a mobile computer-supported collaborative learning environment that helps students engage in active knowledge construction.

Because of the advancing and readily available mobile technologies, some unique interaction experiences such as mobile augmented reality (AR) can be integrated into the collaborative learning environment to promote a situated learning experience. Mobile AR is a promising tool for teaching and learning because of its ubiquitous availability and the strong computing power built into ultra-portable devices (Hsu, Ching, & Snelson, 2014). Dunleavy and Dede (2014) categorized mobile AR into two types: Location-aware AR and vision-based AR. Both types of mobile AR support the situated and immersive perception of a complex concept (or process) by relating real-world objects and “virtual” digital information. Vision-based AR presents the media to learners when they point the camera in a mobile device to certain objects (e.g., QR Code, images). In this study, we employed vision-based AR via Aurasma. This application allows learners to first *create* instructional videos and animations as virtual information artifacts associated with an everyday object or phenomenon, and then *share and review* these multimedia information artifacts (called Aura) with peers when they point their in-device camera to the designated or tagged objects.

Existing literature on using text-based discussion forums has indicated its inadequacy in enabling information search and synthesis, social-cultural relationship development, or multimodal communication (Ke & Chávez, 2013). Emerging web conferencing technology, such as VoiceThread, can act as a multimodal, *mobile-accessible* alternative for asynchronous discussion forums. VoiceThread (VT) is a web-based application that allows learners to place collections of media like images, videos, and documents at the center of an asynchronous discussion, and enables commenting using a mix of text, audio, and video recordings (Ching & Hsu, 2013). In spite of its promise in affording a multimodal and media-centric interaction, research on using VT in the setting of computer-supported collaborative learning is lacking (Ching, 2014).

Constructionism and enactivism learning theories argue that learners actively construct knowledge out of their experiences, especially when they are engaged in building objects (Kafai, 1995; Li, 2012; Papert, 1980). Situating such a learning-by-making approach in the collaborative learning context, the activities of AR artifact creation, sharing, and VT-based peer critique can engage participants in constantly articulating, checking, and constructing content-specific mental models. Simultaneously, educational AR creation and VT-based peer critique can act as meaningful events of technology-supported learning and support technological understanding in an activity-based, pragmatic way. They should potentially promote the integrated development of content and educational technology skills, which compose an essential competency for teaching and learning in the 21st century (Finger, Jamieson-Proctor, & Albion, 2010). The exemplification of such a

* Corresponding author.
E-mail addresses: fke@fsu.edu (F. Ke), hsu@boisestate.edu (Y.-C. Hsu).

http://dx.doi.org/10.1016/j.iheduc.2015.04.003
1096-7516/

content-based technological competency in the education setting is the technological pedagogical content knowledge (TPACK) (Koehler & Mishra, 2009).

TPACK is considered the specialized, highly applied knowledge that is “situated, event-structured, and episodic” and hence not easily learned or taught (Harris & Hofer, 2009, p. 4087). Research exploring the ways to help students to build and use TPACK is still at an early stage. Among the early efforts, learning by developing (or making) technology-integrated instructional artifacts is an approach found promising for TPACK development (Harris & Hofer, 2011; Koehler, Mishra, & Yahya, 2007). Educational AR artifact creation with collaborative review/critique can act as a mobile-accessible technique of the learning-by-making approach for TPACK.

Therefore, in this exploratory study we examined the effectiveness of smartphone-based collaborative learning activities, comprising augmented reality (AR) artifact creation and VT-based discussion, in reinforcing the technological pedagogical content knowledge (TPACK) of teacher education students or pre-service teachers. Particularly, two research questions were addressed: (1) Will participating in mobile AR artifact creation with peer discussions, in comparison with mobile media artifact viewing with peer discussions, better improve the TPACK of teacher education students? (2) What features of the mobile-accessible learning tools support collaborative learning for TPACK development?

2. Literature review

2.1. Mobile augmented reality for learning

Augmented reality (AR) refers to the combination of virtual, overlaid information (e.g., text, images, video clips, sounds, 3-dimensional models, & animations) with real world objects to enhance the user's learning about and the interaction with the physical environments. For example, a location-based AR mobile app, Wikitude, leverages the built-in GPS in mobile devices to track a user's real world location and present contextually relevant virtual data of the surrounding landmarks (e.g., buildings, parks, and stores). AR applications can also work without location restriction and utilize real world images and objects as “triggers” to activate digital information overlay to support learning. For example, the Aurasma app allows its users to view “Aura” – a multimedia artifact that can be an animation or a video clip – by pointing their mobile devices to a designated real-world trigger. Aurasma users can create their own Auras to anchor virtual multimedia overlays in real-world objects, by choosing or capturing an image as the activator and then connecting it with a pertinent animation or video. The user-made Auras can later be published and shared with others through the mobile Aurasma social network; a shared Aura will be presented once a mobile device identifies the trigger image.

The vision-based, digital-authorship-oriented mobile AR application holds great potential for educators because it provides learning that is active, contextually relevant, and closely and immediately related to the learners' environment (Billinghurst, Kato, & Poupyrev, 2001; Bower, Howe, McCredie, Robinson, & Grover, 2014). Yet compared to location-based mobile AR applications and studies (e.g., Dunleavy, Dede, & Mitchell, 2009; Huizenga, Akkerman, Admiraal, & Dam, 2009), studies of vision-based mobile AR are relatively few. In a recent review, Cheng and Tsai (2013) reported that vision-based AR promotes spatial ability, practical skills, and conceptual understanding in science education. In a study by Bressler and Bodzin (2013), middle school students collaboratively played an inquiry-based mobile AR game by using mobile devices to scan QR (quick response) codes to access game-related information, solve a detective case, and learn forensic science. The study reported that the group play of the vision-based AR game can increase students' science interest and their collaboration skills. In another study, Furió, González-Gancedo, Juan, Seguí, and Costa (2013) also utilized vision-based AR to present science information to school students (aged 8 to 10), by using a selection of pictures as “markers” in a classroom to activate multimedia presentations on the related content topics. Furió et al. (2013) reported that the size and weight of mobile devices did not influence students' acquired knowledge, engagement, satisfaction, ease of use, or AR experience.

It should be noted that prior research on mobile AR, including the aforementioned studies, generally focuses on information provision and overlay as the major functions of mobile AR applications. Hence learning is mainly the collection and comprehension of pre-packaged information. Such an AR-based learning experience, as argued by Bower et al. (2014), may fail to support “higher order integrative thinking skills such as analysis, evaluation, and creation” (p. 4). Although recent mobile AR applications (e.g., Aurasma) encourage digital authorship, research on the practice of making learners designers with mobile AR is lacking. Besides, prior research of mobile AR generally focused on K-12 school students. Research on the pedagogical applications of vision-based mobile AR in higher education, especially for pre-service teachers who are in need of pedagogical and technological knowledge of augmented reality, is warranted.

2.2. Mobile CSCL

Mobile computer supported collaborative learning (MCSCL) refers to the practice of meaning making by groups of individuals in the context of joint activity that is mediated through mobile computing (Stahl et al., 2006; Zurita & Nussbaum, 2004a, 2004b). In a recent review of empirical studies on MCSCL, Hsu and Ching (2013) found multiple ways in which mobile computing mediates meaning making in a joint activity. Particularly, wirelessly interconnected mobile devices can: 1) facilitate information sharing and instant feedback provision (e.g., Zurita & Nussbaum, 2004b); and 2) provide individuals with different portions of a group learning task and coordinate task-oriented interaction (e.g., Boticki et al., 2011; Roschelle et al., 2009).

Most of previous studies of MCSCL were conducted in K-12 settings. For example, in the work of Zurita and Nussbaum (2004a, 2004b) that focused on reading literacy and numeracy, mobile devices enhanced face-to-face collaborative learning activities by enabling digital information sharing, providing instant feedback on individual and group's task performances, and facilitating first-graders' collaborative knowledge construction and internalized individual understanding. Boticki et al. (2011) helped primary school students in Singapore learn mathematics by using wirelessly connected mobile devices to support student-led, emergent learning groups. Via mobile devices, students reviewed fractions presented on the screen, identified peers with complementary fractions, and sent group invitations to peers to form a group and complete the task of fraction adding. The work of Boticki et al. (2011) is in line with that of Roschelle et al. (2009), who also used mobile devices to present multiple portions of a fraction problem to students in a learning group to activate peer discussion and collaborative problem solving.

Although there is empirical evidence suggesting that learners actively participate in mobile collaborative learning activities, research on creation-oriented, design-based mobile collaborative learning is lacking. In the studies reviewed, learning content was generally delivered to learners, which falls short of the Web 2.0 spirit that encourages and empowers learners to create, share (what they created), and communicate (about what they created) through the Web, especially the mobile Web. Prior research on MCSCL also lacks studies that use mobile-accessible, multimodal social media (e.g., VoiceThread) to promote interaction, and studies that expand the context to higher education (Hsu & Ching, 2013).

2.3. Learning by making

Dewey (1958) argued that knowing and doing are tightly associated, and as a result, learning needs to take place in the context of activity and involves solving problems in the process of trying to accomplish a meaningful goal (Shaffer, 2004). The task of making and sharing a content-specific, educational artifact is a problem-solving process, in which learners conduct inquiries and information searching, actively represent and apply domain knowledge, reflect on experiences, and engage in self-explanation and communication (Ke, 2014). Thus knowledge and skills acquired in such a task will be more transferable to future situations (de Vries, 2006).

Earlier works on constructionism (Papert, 1980) and learning by making indicated the potential of using artifact making as a learning inquiry and a meaningful context for learners to implement and ground content knowledge, computing skills, and related critical thinking (de Vries, 2006; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kafai, 1995; Ke, 2014; Kolodner et al., 2003). Recently, Li (2010, 2012) has argued for a close connection between the affordance of a learning-by-making environment, a learner's capacity of action and perception, and a participatory culture in knowledge development. In her exploratory case study, Li (2012) reported that involving teachers in developing an educational game enabled them to re-conceptualize pedagogy and teaching practice. Bower et al. (2014) described a learning by making project in which sixteen high school students used Aurasma in pairs to create vision-based AR overlays (e.g. written, image, and video explanations) that could be triggered by sculptures in a park. Their descriptive findings indicated that making AR artifacts would develop students' visual arts capabilities and engage them in deep thinking about technology. A future research direction suggested by Bower et al. (2014) is to involve teachers in AR-driven, learning by making activities.

However, our recent review of the prior research on learning by making did not indicate a published study experimentally comparing learning by making (or design) with a conventional learning approach (e.g., learning from existing artifacts or worked examples). Although quite a few previous studies examined the differential effects of constructivism versus conventional learning approaches (e.g. Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Lord, 1999; Tynjälä, 1999), research examining constructionism and learning by making specifically in comparison with other learning approaches is missing.

In this study, mobile AR artifact creation, sharing, and discussion, in comparison with mobile-friendly media review and discussion, is an activity that embodies the perspectives of constructionism and learning by making. It is speculated that the process of making a content-specific, educational AR artifact will enable learners to externalize, self-check, and constantly refine their prior beliefs and mental frameworks on the pedagogical integration of technology and the targeted content topic.

2.4. Technological pedagogical content knowledge (TPACK) development

Building on Shulman's construct of pedagogical content knowledge (Shulman, 1987), technological pedagogical content knowledge (TPACK) is a triad construct representing teacher knowledge for technology integration, or the knowledge intersections among three core components — technology, pedagogy, and content (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Within the framework of TPACK, pedagogical knowledge (PK) refers to teachers' knowledge about the processes and practices of methods of teaching and learning; content knowledge (CK) is teachers' knowledge about the subject matter to be learned or taught; and technology knowledge (TK) refers to an understanding and mastery of information technology applied productively at work (Koehler & Mishra, 2009).

While researchers and practitioners quickly endorsed the notion of TPACK, prior research has generally focused on describing or explaining the construct (e.g. Archambault & Barnett, 2010; Chai, Koh, & Tsai, 2010; Graham, 2011; Harris & Hofer, 2011). Studies examining the learning environment and activities that promote TPACK development for in- or pre-service teachers are scarce. Koehler et al. (2007) hosted a faculty development design seminar in which faculty members formed design teams with their students to co-develop online courses. Descriptive findings suggested that participants developed a richer conception of TPACK with a deeper understanding of the connections among technology, pedagogy, and content. Koh and Divaharan (2011) examined the TPACK development of pre-service teachers in information communication and technology (ICT) instruction. They reported that ICT product critique and peer sharing should be emphasized in a TPACK intervention. In general, the earlier efforts examining TPACK instructions endorse the learning by making (or design) approach and reported it as an active and effective technique to develop deeper understanding of TPACK (Harris & Hofer, 2009; Koehler et al., 2011).

Based on prior research on learning by making and TPACK development, we speculated that making mobile, educational AR artifacts along with VT-based product critique would facilitate active and meaningful interactions between learners and the embedded content topic, between learners and the mobile computing technology to be utilized and integrated, and between learners and peers during artifact review and critique. This practice hence might promote contextualized and integrated understandings of the content, technology, and pedagogy knowledge bases.

3. Method

A mixed-method study was conducted to evaluate the impact of the mobile collaborative learning activities on enhancing the TPACK of the participants and science knowledge retention. We adopted an explanatory, mixed-method research approach in order to develop a real-life contextual understanding and an integrated perspective of the mobile AR- and web-conferencing-supported mobile collaborative learning (Creswell, 2014; Johnson, Onwuegbuzie, & Turner, 2007). Forty teacher education students from the college of education at a land-grant university in the U.S., with around 74% being female and a median of 3.5 years in college, participated in the study. Participants were randomly assigned to two study groups, of whom 34 completed all study activities.

3.1. Intervention and procedure

All study participants performed mobile-accessed, online learning activities in a self-regulated way, at their own places over two weeks. The intervention commenced with an online training module that was comprised of YouTube movie clips and web tutorials that explained the structure of the mobile learning activity, demonstrated the usage of the VoiceThread mobile site. Students were presented the design heuristics of creating an instructional video or an informative animation via Aurasma.

The study procedure for the two comparison groups is outlined in Fig. 1. In Study Group 1, participants were involved in mobile AR artifact creation, sharing, and then VoiceThread-based discussions. Specifically, they were requested to create a collection of smartphone-based augmented reality videos or animations via the free mobile software (Aurasma Lite) to illustrate and teach the concept and calculation of buoyant force. They then used the VoiceThread mobile site to share and critique the videos with each other. A semi-structured activity protocol, including the design criteria of the videos or animations to be developed and the requirements of the peer critique process, was provided to the participants.

Participants in Study Group 2 did not experience Aurasma-based mobile AR; they were involved in reviewing existing (instead of creating) mobile multimedia artifacts. Specifically, they were requested to use their smartphones to watch a selection of mobile-friendly videos and animations on buoyant force that were created by credible educational organizations or resource sites (e.g. *Khan Academy*, *ExploreLearning*). They then used the VoiceThread mobile site to share their understandings and critiques of the videos with each other. A

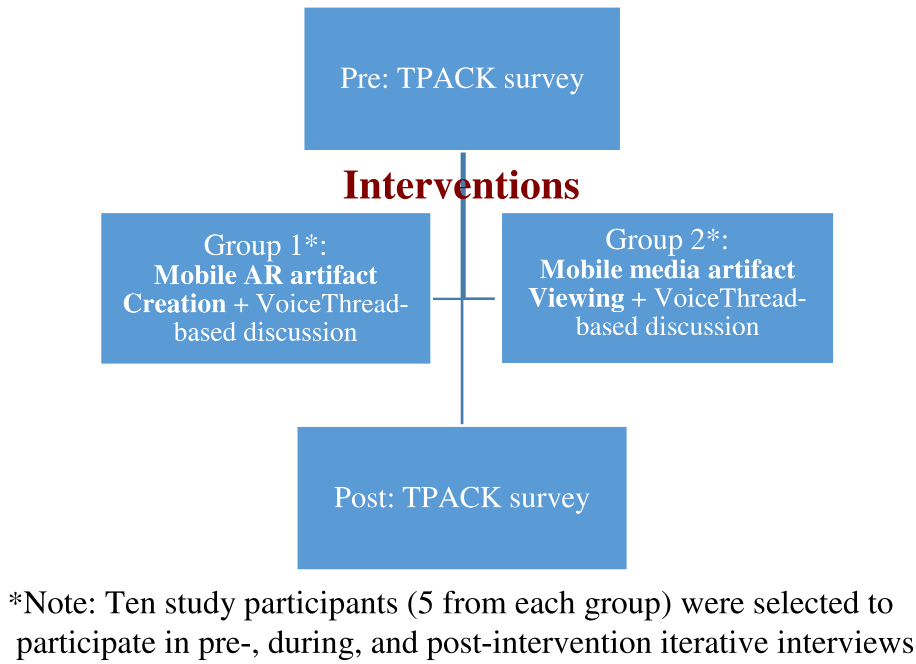


Fig. 1. Procedure of the study.

semi-structured activity protocol, including the information and requirement of the videos/animations viewing and peer critique process, was provided to the participants.

3.2. Instrument, data collection, and analysis

The Survey of Pre-service Teachers' Knowledge of Teaching and Technology (Schmidt et al., 2009, 5-point Likert scale, $\alpha = .91$ in this study) was adopted to evaluate pre-service teachers' self-reported TPACK development. In comparison with other instruments measuring TPACK (e.g., Archambault & Crippen, 2009; Graham et al., 2009; Lee & Tsai, 2010), the survey by Schmidt et al. (2009) was interdisciplinary (covering the areas of mathematics, social studies, science, and literacy). It was empirically validated by multiple studies (Chai et al., 2010), with consistently high Cronbach alphas of .80+ for the full scale and its component sub-scales (e.g., TK, CK, PK, TPK, TPACK). A shortened version of the survey (26 items, focusing on science-related TPACK) was used in this study, with the items assessing the areas of math, social studies, and literacy left out.

All study participants were requested to complete the web-based TPACK survey before and after the intervention. Paired-samples *t*-test and one-way ANCOVA analyses were conducted with the pre- and post-intervention survey responses to examine whether MCSCL activities promoted self-reported TPACK and whether the two MCSCL conditions would differ in influencing the self-reported TPACK improvement.

Ten study participants were selected to participate in pre-, during, and post-intervention iterative interviews. The selected interviewing participants represented diverse learner groups of activity, gender, age, and prior knowledge/skill. The interviewing was semi-structured following a generic interviewing protocol. Example interview questions were, "What is your experience of Aura creation and sharing (or VoiceThread-based discussion)? Could you tell me what you did and how you felt?" "What is your experience with mobile collaborative learning in this study? In what ways are you satisfied, and not satisfied?" "How do you see your experiences impacting your future teaching?" "If you were an instructor, how would you, based on your experience, redesign these mobile learning activities?"

The Aurasma-Lite-based videos or animations created by the study participants were collected for an artifact analysis to provide descriptive evidence on the TPACK development. Participants' VoiceThread-based online interactions with time stamps were also archived and collected for a later qualitative content analysis that in an inductive way, explored the emerged patterns or categories of the main topics in discussions (i.e., in relation to the content, technology, pedagogy, or an integrated understanding).

A qualitative thematic analysis was then conducted with the interview, media artifact, and online discussion analysis results to synthesize and extract salient themes on how participants interacted with and perceived mobile-accessible learning tools and activities, thus informing on the characteristics of a mobile learning tool that supports collaborative learning for TPACK development.

4. Results

4.1. TPACK development

The paired-sample *t*-test with the pre- and post-study TPACK responses indicated a significant result, $t(33) = -3.12$, $p < .01$, with a statistically significant improvement in self-reported TPACK competency of all study participants from pre-intervention ($M = 95.1$, $SD = 12.1$) to post-intervention ($M = 99.2$, $SD = 13.5$).

An ANCOVA analysis (with the pre-survey as the covariate) examining the effect of mobile collaborative learning (MCSCL) intervention conditions or groups on the TPACK survey result revealed no statistical significance. This finding did not indicate a differential effect of mobile AR artifact design with VoiceThread-based (VT-based) peer discussion, in comparison with mobile media artifact viewing with VT-based peer discussion, in promoting the overall TPACK survey result. It should be noted that this insignificant finding on the effect of MCSCL conditions on the TPACK survey result is based on a relatively small sample and there may be a ceiling effect when the sample had a high-level pre-intervention TPACK competency.

A MANCOVA analysis, with the pre-intervention subscale responses as the covariates, was then conducted to examine the effect of the MCSCL condition on the subscale results (*Technology* knowledge, *Pedagogy* knowledge, *Content* knowledge, *Technological Pedagogical* knowledge or *TPK*, and *Technological Pedagogical Content* knowledge or *TPACK*) of the TPACK survey. The Levene's test of equality of error variances was not significant, indicating that the assumption that the error variance of the dependent variable is equal across groups was met. The multivariate result for the effect of the MCSCL condition approached statistical significance, $F(5, 23) = 2.40$, $p = .068$, $\eta^2 = .34$. Univariate tests indicated an effect of the MCSCL condition on TPK (4-item, $\alpha = .81$) and TPACK subscale (4-item, $\alpha = .81$) results, $F(1, 27) = 3.99$, $p = .056$, $\eta^2 = .128$ and $F(1, 27) = 4.15$, $p = .052$, $\eta^2 = .133$ respectively. The tests indicated a slight advantage of the mobile AR artifact *design* condition over the mobile media artifact *viewing* condition on the two subscale measures. On the other hand, the univariate analysis with the subscale of the *Content* knowledge (3-item, $\alpha = .85$) indicated a trend toward the advantage of the mobile media artifact viewing condition over the mobile AR artifact creation condition, $F(1, 27) = 3.06$, $p = .09$, $\eta^2 = .09$. The descriptive statistics are provided in Table 1 and shown in Fig. 2.

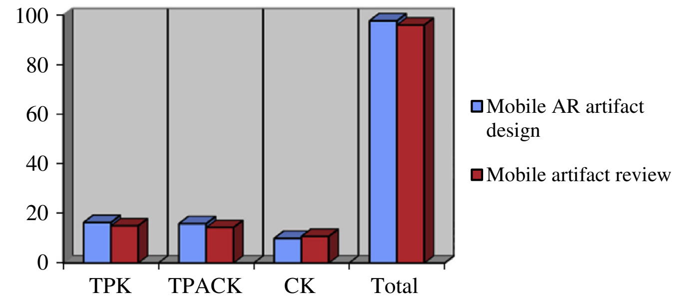


Fig. 2. Group comparison in the TPK subscale, TPACK subscale, CK subscale, and TPACK full scale results.

The findings above suggest differential effects of the two MCSCL conditions on different components of the self-reported TPACK competency. Specifically, mobile AR artifact creation with VT-based peer discussion promoted the integrative *TPK* and *TPACK* competency development, whereas mobile media artifact viewing with VT-based peer discussion seemed to better support the content knowledge competency. It is possible that mobile AR artifact creation would involve learners more in exploring the technological content presentation and pedagogy whereas mobile media viewing would focus learners in comprehending the subject matter itself. These findings and interpretations can be corroborated and elucidated by the following salient themes emerged from the qualitative data, which illustrated the salient features or affordances of the mobile friendly learning tools and activities in supporting collaborative learning for TPACK development.

4.2. Conceptual representation and comprehension in mobile AR artifact creation and mobile media artifact viewing

4.2.1. AR artifact creation for conceptual representation

Multiple forms of cognitive representation of the target concept (i.e., buoyancy) appeared in mobile AR artifacts created by participants, among which 10 were *illustrative* (i.e., conceptual demonstration via an experiment demo or a graphic animation, as Fig. 3 illustrates), three were *discursive* (i.e., conceptual presentation via textual and/or voiceover explanations), and six included both representation elements (see Fig. 4). These conceptual representations highlighted either *associative* (i.e., in natural language) or *symbolic* (i.e., in mathematical symbols and equations) descriptions of the content (Hummel, 2010).

The interview results also confirmed that participants of the AR creation group were involved in reviewing, selecting, and intermittently connecting different forms of content representation when creating instructional AR artifacts on buoyancy. Specifically, these participants reported that instructional Aura development "refreshed their memory of the buoyancy law" and "deepened the understanding" because they had to "reread the content," "conduct different experiments, such as adjusting the volume of water and the objects to float, to present the final product," and "provide oral explanations in addition to a written statement of the concept." In other words, AR artifact creation challenged participants to actively experience and present the concept in a flexible and concrete format, thus enabling a meaningful interaction with the subject matter.

On the other hand, due to the Aurasma's file-size requirement all AR artifacts created were short (30 s to 1 min), which constrained the scope and depth of the content represented. The AR artifacts created, as observed and self-reported, presented more of a generic introduction than an extensive explanation of the concept (the buoyancy law). We also found that not all AR artifacts managed to provide a meaningful and semantic connection between a real-world trigger and the virtual instructional messages. For example, an Aura used a mathematical symbol as the trigger to activate a lecturing video filled with mathematical equations and calculations. In comparison, another Aura used everyday objects (e.g., a lemon or an egg) as the triggers to activate an illustrative video demonstrating how these objects would follow the buoyancy law to float or sink in water of different volumes or properties. The former example demonstrated a process of conceptual representation within the world of abstract symbols, whereas the latter went from the world of everyday scenarios into the world of symbols. Participants making Auras of the latter type, in comparison with others, were fewer but showed a more positive disposition toward composing authentic problems and actively integrating AR in science teaching.

4.2.2. AR artifact creation versus media artifact viewing: presentation or comprehension

In comparison with the media-viewing group, the AR creation group appeared to be more active in reading and participating in VoiceThread (VT) peer discussions; each voice thread had an average of 9.23 peer readings and 2.38 peer responses. Consistently, interviewed participants in the mobile AR creation group self-reported more on-task time in both artifact interaction and peer discussion than those in the mobile media viewing group.

The content analysis of voice threads indicated that Aura-creation-oriented peer discussions focused on how the subject matter should be better presented and/or explained, via what representation formats or objects, for teaching and learning. Such a pattern was illustrated by the following comments on the same VT thread:

> "I think this is a great clip to explain buoyancy. Using something familiar, like a hand, could be a good way to make the concept relevant. After an audio clip is added providing a quick explanation connected to buoyancy, I think this would be a great aura!"
> "This video works well to show how the water spills out from the glass when a solid is immersed. However, we also want to explain how to calculate the weight of an object. It would be easier with a solid that we can leave on the glass—not a hand."
> "Using narration while immersing the hand would be helpful and would correlate to e-learning principles."
> "As some of the other comments stated, I think it would be better for the video if the instructor sort of explained what is happening while putting the hand in the cup. But I also think that instead of a hand

Table 1
Descriptive statistics.

	MCSCL condition	Mean[a]	Std. error	N
TPK	Mobile AR artifact design	16.39	.42	19
	Mobile artifact review	15.05	.48	15
TPACK subscale	Mobile AR artifact design	15.93	.49	19
	Mobile artifact review	14.35	.56	15
CK	Mobile AR artifact design	9.97	.34	19
	Mobile artifact review	10.77	.39	15
TPACK total	Mobile AR artifact design	97.78	2.59	19
	Mobile artifact review	96.07	2.92	15

[a] Adjusted means with pre-intervention subscale scores as covariates.

Note: The aura on the left demonstrated an everyday example of buoyancy by showing how the water spills out from the glass when a hand is immersed. The aura on the right illustrated a multi-step experiment showing an egg that sank in cold water, floated above cold water added with salt, and floated in the middle of the glass when warm water was added.

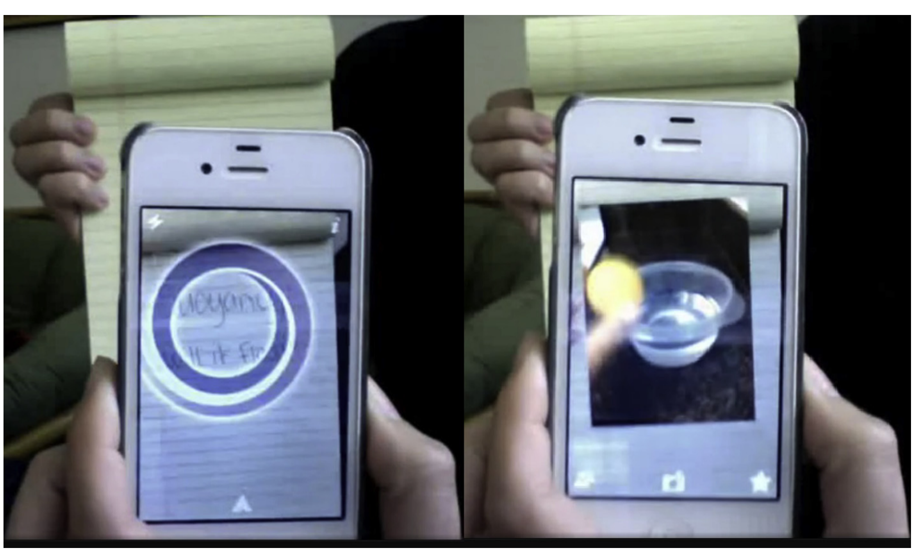
Fig. 3. Examples of illustrative representation of buoyancy in Auras created.

maybe it should be a smaller heavy object so the viewers can actually see the water level rising and falling for the object going in and out of it, so they can better understand the concept. Putting the hand in there is a little hard to tell what is going on."

In contrast, the VT posts of participants in the media-viewing group were filled with reflections and interpretations of the concept of buoyancy after reviewing the premade, mobile-accessible videos/animations:

"This picture explains the law of buoyancy because if an object contains a large amount of density then it will cause the object to sink. The fluid or pressure of an object will increase with depth because of the weight of the object. Buoyancy is very interesting to me. I always wondered how can a human being float in a pool of water but a rock will sink when it is dropped in a pool of water."
"I was fascinated by the Introduction to Archimedes' principle and buoyant force on the Khan Academy site (an educational web site that provided premade, mobile-accessible instructional videos), and amazed that I could actually almost understand it because of the way it was demonstrated and talked! Very cool!"
"After watching it, I felt that I am a lot smarter."

It appeared that studying a collection of premade, high-quality mobile-accessible artifacts on the buoyancy law, in comparison with



Note: In the example above, an image of notepad would trigger the presentation of a multimedia aura that integrated voiceover and written explanation of buoyancy with an illustrative experiment (i.e.,putting Ping-Pong ball in a cup of water).

Fig. 4. Integration of discursive and illustrative representations of buoyancy in an Aura.

creating one's own mobile artifact, involved participants in comprehending the subject matter itself rather than exploring the presentation methods and the pedagogy.

4.2.3. Tools' socio-technical affordance for mobile collaborative learning

Habitualness, *shared-ness*, and *intuitiveness* emerged as three salient features that depict the desirable "socio-technical affordances" (Vatrapu, 2008) of a mobile collaborative learning tool. These features represent relational properties of a mobile learning tool that facilitate learners' interaction with technology and peers to reinforce the integration of collaborative learning with everyday activities.

4.2.3.1. Habitualness. *Habitualness* refers to the extent to which a mobile tool can act as a "comfortable," "familiar," and "part of life" interface for collaborative learning. It was observed that participants, while performing peer discussions via VoiceThread (VT), had simultaneously used Google Drive and email as supplementary tools to support content elaboration and reference sharing. The interview results indicate that study participants tended to use a novel tool (e.g., VT) as a peripheral layer to their habitual collaborative-work systems (e.g., Google Apps). As one student commented, "I am used to having Google Drive and emails for daily work. It's convenient to coordinate them with VoiceThreads among group-mates." Related to this pattern of habitualness was the observation that participants frequently chose to use text feedback rather than commenting via voice in VoiceThread. They explained, "Voice commenting is novel and challenging," "I feel more comfortable typing," and "I intended to only listen to the latest voice comment; but if they are text threads, I would expand and read all of them." These comments imply the lack of habit forming in using media-rich, multimodal communications for mobile collaborative learning. At the same time, these findings suggest that frequently involving participants in mobile learning via emerging social or creative media may encourage their habit formation and learning/instructional practice with these tools, thus enhancing participants' assurance and technological pedagogical content understanding of emerging technologies.

4.2.3.2. Shared-ness. Another salient theme in Aurasma and VoiceThread as the tools of mobile collaborative learning was the degree of *shared-ness* or connectedness needed for the converging of individual effort and intelligence. Both tools appear to emphasize a cooperative-work process — publishing or sharing of individual works for peer comments. As stated by the participants, the tools miss a "shared work space" that allows for "direct customization and building on others' work." In consequence, the degree of interactive discourse in VT was insufficient in both study groups: The posts responding to or adding on to peer comments were present in only around 37% of the Auras shared, and the peer comments corresponding with each other were rare in the media-viewing group. Besides, varied smartphone platforms of participants created minor differences in the interface of tools or the process of Aura making and sharing, leading to confusion during peer demonstration. Frequently participants reported difficulty in publishing, seeking, or displaying the Auras shared in Aurasma's mobile community, as highlighted by this example quotation, "Ok, so this image is just a base of the Aura. I don't know if it is just my app but if there is supposed to be animation then my app doesn't show it." The aforementioned shared-ness issues may have negatively affected participants' participation in collaborative meaning making or knowledge co-construction for TPACK development.

On the other hand, there were self-reported efforts of some participants in building on others' ideas during Aura creation, "This is really neat! I was thinking of making a similar video." Although Auras created seemed to follow a common theme in illustrating buoyancy — sinking or floating varied objects in liquids, there was an obvious increased complexness in the types of objects and the sinking/floating process depicted and explained in Auras created in the later phase. Specifically, the number of frames or units embedded within each tagged video/animation increased in Auras developed, from one frame initially to six frames later. For example, an earlier Aura tried to illustrate the concept of density and buoyancy by showing a sinking egg and a floating Ping-Pong ball in a glass of water. A later Aura created by another participant then extended this idea by introducing varied types of water (cold versus hot) and additional material (salt), which then illustrated a multi-step experiment showing an egg that sank in cold water, floated above cold water added with salt, and floated in the middle of the glass when warm water was added. The observation suggested that Aura creation and sharing would provide opportunities for participants to critically reexamine their conceptual understanding of the subject matter and enable them to build on one another's ideas to construct more sophisticated ways of technology-based content representation. This finding is consistent with the quantitative finding of the advantage of AR artifact creation in supporting the integrative development of TPACK.

4.2.3.3. Intuitiveness. Aurasma's file-size requirement and its low sensitivity of image or pattern recognition led to a *non-intuitive* process of mobile AR design. Participants complained that there was a conflict between high-quality content presentation and the file-size limit of sharable Auras. Some participants reported that they had to sacrifice the presentation of content depth or had to use desktop applications to streamline a video or animation before uploading it to Aurasma. Participants also complained about the lack of freedom in selecting everyday scenarios for conceptual presentation due to the non-intuitive operation that might involve multiple trials and failures in making the in-device camera recognize a solid-object tag. As a result, they resorted to simplistic symbols or texts for the tag and settled on a simplified conceptual introduction for the Aura-based content presentation. Such a pattern may have demotivated or constrained their efforts in content exploration, and reduced their involvement in connecting conceptual representations (i.e., integrating associative and symbolic forms of representation). This pattern helped to explain the quantitative finding of the disadvantage of AR artifact creation (compared with media artifact viewing) in supporting content knowledge development.

5. Conclusions and discussion

The study findings indicate that both mobile collaborative learning conditions have promoted self-perceived TPACK development for the participating pre-service teachers. There is not enough evidence suggesting that participating in mobile AR artifact creation with VoiceThread-supported peer discussions, compared with mobile media artifact viewing with VT-supported peer discussions, will better promote the overall TPACK development for teacher education students. However, the study found that mobile AR artifact design tends to better promote integrative competencies that connect technology, pedagogy, and/or content knowledge (i.e., TPK and TPACK); the former also better facilitates peer-discussion participation. Conversely, the activity of mobile media artifact viewing appears to better promote the componential competency of content knowledge. Such a finding partially supports the previous studies on the effectiveness of the learning-by-making approach in creating a connected, integrative understanding of TPACK (Harris & Hofer, 2009; Koehler et al., 2007; Koh & Divaharan, 2011; Li, 2010, 2012). At the same time, it extends the prior research by suggesting that the conventional approach of learning by viewing existing media artifacts (or examples), in comparison with learning by making AR artifacts, tends to better promote content competency.

A potential reason of the aforementioned findings is that acting as an author of an educational AR artifact tends to make participants assume the role of a teacher and a presenter, whereas acting as a user during mobile media viewing will make participants more a learner and spectator. Correspondingly, mobile AR creation has steered participants' effort and attention toward the exploration and discussion of the technology-integrated content representation and communication (i.e. an integrated understanding of content-specific, technological pedagogical knowledge), whereas mobile media viewing appears to engage them in the comprehension of the subject matter itself (thus promoting content competency).

It is also observed that certain technical limitations associated with Aurasma in the mobile AR production (e.g., file-size constraint and low sensitivity in trigger recognition) has reduced the degree to which one can semantically and flexibly represent the subject matter. Thus, mobile AR production fails to provide participants with sufficient action-taking and meaning-making opportunities — opportunities of "discovering or confronting their (mis)conceptions" for content knowledge development (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998, p. 16). Such an observation is consistent with prior research that a critical design consideration for the learning-by-making pedagogy is to integrate the opportunity of content representation and enhance the learner–content interaction (Ke, 2014; Kolodner et al., 2003).

The finding on the advantage of mobile AR creation in facilitating peer discussions is consistent with the literature on learning by design and mobile AR that an AR-supported, authorship-oriented inquiry promotes collaborative skills (Bressler & Bodzin, 2013; Bower et al., 2014). The prior research on the nature of the TPACK framework has emphasized the importance of the intersection and inseparability of the domains of pedagogy, content, and technology (Archambault & Barnett, 2010; Chai et al., 2010). A recent survey study by Koh, Chai, and Tsai (2014) then indicated that teachers' perceptions of technological pedagogical knowledge, among all TPACK components, had the largest positive relationship with and accounted for the majority of the variance in their constructivist-oriented ICT competency. Considering these standpoints and the current study findings, mobile AR artifact creation should be considered and used as a promising element of mobile collaborative learning to promote the integrative TPACK development.

According to Vatrapu (2008), a technology-enhanced collaborative learning environment can be characterized by two socio-technical interactions: interacting with technology and interacting with people via technology. The socio-technical affordance thus refers to the properties of the technology that enable action taking or meaning making during the learning interactions. The study findings implied that the aspects of habitualness, shared-ness, and intuitiveness may constitute the socio-technical affordance of a mobile tool for computer-supported collaborative learning. Specifically, emerging technologies such as VoiceThread and Aurasma need to become part of users' habitual tool system to act as the platform for mobile CSCL learning activities. The lack of an intuitive interface for shared work synthesizing or editing in VoiceThread and Aurasma seems to discourage the participation of interactive dialogues and hence reduce the chance of collaborative knowledge construction. To enable multi-modal communication and collaborative learning through AR artifact making, mobile tools like VT and Aurasma are in need of more intuitive and co-constructive features that will not only facilitate interactions but also manage and regulate the collaborative meaning-making process (Stahl, 2006).

5.1. Implications

The findings of this exploratory study indicate the beneficial effects of mobile collaborative learning activities, including mobile AR artifact creation, media artifact viewing, and VT-supported multimodal discussions, in reinforcing the technological pedagogical content knowledge (TPACK) for pre-service teachers. Future research should further examine the differential effects of learning by making (e.g., AR artifact creation) versus learning from examples (e.g., viewing existing media artifacts) on integrated and componential TPACK competencies development, with the on-task time, alternative mobile AR applications, and other collaborative learning tools considered.

This study has highlighted the salient attributes of a mobile-accessible learning tool that supports socio-technical, meaning-making interactions for active and collaborative knowledge construction. These attributes – *habitualness*, *shared-ness*, and *intuitiveness* – can act as preliminary heuristics to guide educational practitioners in designing, selecting, and evaluating emerging mobile-accessible technologies in the context of computer-supported collaborative learning. The specific implications for implementing AR-integrated, mobile-accessible collaborative learning activities include: (1) training on and actively involving learners in the usage of emerging social and creative media to foster their habit formation and competence in innovative-technology-supported learning interactions, (2) creating or providing a shared virtual workspace that enables learners to collaboratively work on a mobile artifact or build on others' perspectives and works during artifact making, (3) selecting mobile applications that present less constraints on the mobile equipment and higher flexibility in its authoring and sharing process, so that learners can focus on constructing varied forms of content representation for a deep understanding of the subject matter.

References

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, *103*(1), 1–18.

Archambault, L. M., & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: exploring the TPACK framework. *Computers & Education*, *55*(4), 1656–1662.

Archambault, L., & Crippen, K. (2009). Examining TPACK among K-12 online distance educators in the United States. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 71–88.

Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The magicbook—moving seamlessly between reality and virtuality. *IEEE Computer Graphics and Applications*, *21*(3), 6–8.

Boticki, I., Looi, C. K., & Wong, L. H. (2011). Supporting mobile collaborative activities through scaffolded flexible grouping. *Educational Technology & Society*, *14*(3), 190–202.

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented reality in education—cases, places and potentials. *Educational Media International*, *51*(1), 1–15.

Bressler, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning*, *29*(6), 505–517.

Chai, C. S., Koh, J. H. L., & Tsai, C. -C. (2010). Facilitating preservice teachers' development of technological, pedagogical, and content knowledge (TPACK). *Educational Technology & Society*, *13*(4), 63–73.

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: suggestions for future research. *Journal of Science Education and Technology*, *22*(4), 449–462.

Ching, Y. -H. (2014). Exploring the impact of role-playing on peer feedback in an online case-based learning activity. *The International Review of Research in Open and Distance Learning*, *15*(3), 292–311.

Ching, Y. -H., & Hsu, Y. -C. (2013). Collaborative learning using VoiceThread in an online graduate course. *Knowledge Management & E-Learning: An International Journal*, *5*(3), 298–314.

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). Thousand Oaks, CA: Sage Publications.

de Vries, E. (2006). Students' construction of external representations in design-based learning situations. *Learning and Instruction*, *16*(3), 213–227.

Dewey, J. (1958). *Experience and Nature, Vol. 1*, Mineola, NY: Courier Dover Publications.

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. In M. Spector, D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 735–745) (4th ed.). New York, NY: Springer Academics.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*, 7–22.

Finger, G., Jamieson-Proctor, R., & Albion, P. (2010). Beyond pedagogical content knowledge: the importance of TPACK for informing preservice teacher education in Australia. *Key Competencies in the Knowledge Society* (pp. 114–125). Berlin–Heidelberg: Springer.

Fortus, D., Dershimer, C. R., Krajcik, J. S., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081–1110.

Furió, D., González-Gancedo, S., Juan, M. -C., Seguí, I., & Costa, M. (2013). The effects of the size and weight of a mobile device on an educational game. *Computers & Education*, *64*, 24–41. http://dx.doi.org/10.1016/j.compedu.2012.12.015.

Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, *57*(3), 1953–1960.

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

Harris, J., & Hofer, M. (2009). Instructional planning activity types as vehicles for curriculum-based TPACK development. In I. Gibson (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2009* (pp. 4087–4095). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

Harris, J. B., & Hofer, M. J. (2011). Technological pedagogical content knowledge (TPACK) in action: a descriptive study of secondary teachers' curriculum-based, technology-related instructional planning. *Journal of Research on Technology in Education*, *43*(3), 211–229.

Hsu, Y. -C., & Ching, Y. -H. (2013). Mobile computer-supported collaborative learning (mCSCL): a review of experimental research. *British Journal of Educational Technology*, *44*(5), E111–E114. http://dx.doi.org/10.1111/bjet.12002.

Hsu, Y. -C., Ching, Y. -H., & Snelson, C. (2014). Research priorities in mobile learning: an international Delphi study. *Canadian Journal of Learning and Technology*, *40*(2), 1–22.

Huizenga, J., Akkerman, S., Admiraal, W., & Dam, G. T. (2009). Mobile game-based learning in secondary education: engagement, motivation and learning in a mobile city game. *Journal of Computer Assisted Learning*, *25*(4), 332–344.

Hummel, J. E. (2010). Symbolic versus associative learning. *Cognitive Science*, *34*(6), 958–965.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, *1*(2), 112–133.

Kafai, Y. (1995). *Minds in Play: Computer Game Design as a Context for Children's Learning.* Mahwah, NJ: Lawrence Erlbaum.

Ke, F. (2014). An implementation of design-based learning through creating educational computer games: a case study on mathematics learning during design and computing. *Computers & Education*, *73*, 26–39.

Ke, F., & Chávez, A. F. (2013). *Web Based Teaching and Learning Across Culture and Age.* New York, NY: Springer.

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70.

Koehler, M. J., Mishra, P., Bouck, E. C., DeSchryver, M., Kereluik, K., Shin, T. S., & Wolf, L. G. (2011). Deep-play: developing TPACK for 21st century teachers. *International Journal of Learning Technology*, *6*(2), 146–163.

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: integrating content, pedagogy, & technology. *Computers & Education*, *49*(3), 740–762.

Koh, J. H. L., Chai, C. S., & Tsai, C. C. (2014). Demographic factors, TPACK constructs, and teachers' perceptions of constructivist-oriented TPACK. *Educational Technology & Society*, *17*(1), 185–196.

Koh, J. H., & Divaharan, S. (2011). Developing pre-service teachers' technology integration expertise through the TPACK-developing instructional model. *Journal of Educational Computing Research*, *44*(1), 35–58.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: putting learning by design (tm) into practice. *The Journal of the Learning Sciences*, *12*(4), 495–547.

Kolodner, J. L., Crismond, D., Gray, J., Holbrook, J., & Puntambekar, S. (1998). Learning by design from theory to practice. *Proceedings of the International Conference of the Learning Sciences*, *Vol. 98*. (pp. 16–22) (December).

Laurillard, D. (2009). The pedagogical challenges to collaborative technologies. *International Journal of Computer-Supported Collaborative Learning*, *4*(1), 5–20.

Lee, M. H., & Tsai, C. C. (2010). Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. *Instructional Science*, *38*, 1–21.

Li, Q. (2010). Digital game building: learning in a participatory culture. *Educational Research*, *52*(4), 427–443.

Li, Q. (2012). Understanding enactivism: a study of affordances and constraints of engaging practicing teachers as digital game designers. *Educational Technology Research and Development*, *60*(5), 785–806.

Lord, T. R. (1999). A comparison between traditional and constructivist teaching in environmental science. *The Journal of Environmental Education*, *30*(3), 22–27.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *The Teachers College Record*, *108*(6), 1017–1054.

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas.* New York, NY: Basic Books.

Roschelle, J., Rafanan, K., Bhanot, R., Estrella, G., Penuel, B., Nussbaum, M., & Claro, S. (2009). Scaffolding group explanation and feedback with handheld technology: impact on students' mathematics learning. *Educational Technology Research & Development*, *58*(4), 399–419. http://dx.doi.org/10.1007/s11423-009-9142-9.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge: the development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123–149.

Shaffer, D. W. (2004). Pedagogical praxis: the professions as models for post-industrial education. *Teachers College Record*, *106*(7), 1401–1402.

Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23.

Stahl, G. (2006). *Group cognition: Computer Support for Building Collaborative Knowledge.* Cambridge, MA: MIT Press.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: an historical perspective. In R. K. Sawyer (Ed.), *Cambridge Handbook of The Learning Sciences* (pp. 409–426). Cambridge: Cambridge University Press.

Tynjälä, P. (1999). Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. *International Journal of Educational Research*, *31*(5), 357–442.

Vatrapu, R. K. (2008). Cultural considerations in computer supported collaborative learning. *Research and Practice in Technology Enhanced Learning*, *3*(2), 159–201.

Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes.* Cambridge. MA: Harvard University Press.

Zurita, G., & Nussbaum, M. (2004a). A constructivist mobile learning environment supported by a wireless handheld network. *Journal of Computer Assisted Learning*, *20*, 235–243.

Zurita, G., & Nussbaum, M. (2004b). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education*, *42*(3), 289–314.