Augmented Reality Teaching and Learning

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Abstract

This literature review focuses on augmented realities (AR) for learning that utilize *mobile, context-aware* technologies (e.g., smartphones, tablets), which enable participants to interact with digital information embedded within the physical environment. We summarize research findings about AR in formal and informal learning environments (i.e., schools, universities, museums, parks, zoos, etc.), with an emphasis on the affordances and limitations associated with AR as it relates to teaching, learning, and instructional design. As a cognitive tool and pedagogical approach, AR is primarily aligned with situated and constructivist learning theory, as it positions the learner within a real-world physical and social context while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation.

Keywords

Augmented reality • Mobile learning • Context-aware • Location-based

Introduction

This literature review focuses on augmented realities (AR) for learning that utilize *mobile, context-aware* technologies (e.g., smartphones, tablets), which enable participants to interact with digital information embedded within the physical environment. We summarize research findings about AR in formal and informal learning environments (i.e., schools, universities, museums, parks, zoos, etc.), with an emphasis on the affordances and limitations associated with AR as it relates to teaching, learning, and instructional design.

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There are two forms of AR currently available to educators: (1) location-aware and (2) vision-based. Location-aware AR presents digital media to learners as they move through a physical area with a GPS-enabled smartphone or similar mobile device (Figs. 59.1 and 59.2). The media (i.e., text, graphics, audio, video, 3D models) augment the physical environment with narrative, navigation, and/or academic information relevant to the location. In contrast, vision-based AR presents digital media to learners after they point the camera in their mobile device at an object (e.g., QR code, 2D target). The following scenario provides a contextualized example of both forms of AR:

> As the 7th grade life science student passes by an oak tree in her school playground, software leveraging GPS plays a video on her smartphone describing the various habitats and animals that are found near the tree (location-aware). At the end of the video, the student is prompted to point her phone's video camera at a placard at the base of the tree, which triggers a 3-dimensional model illustrating the anatomical structure of the oak (vision-based).

The potential power of AR as a learning tool is its ability "to enable students to see the world around them in new

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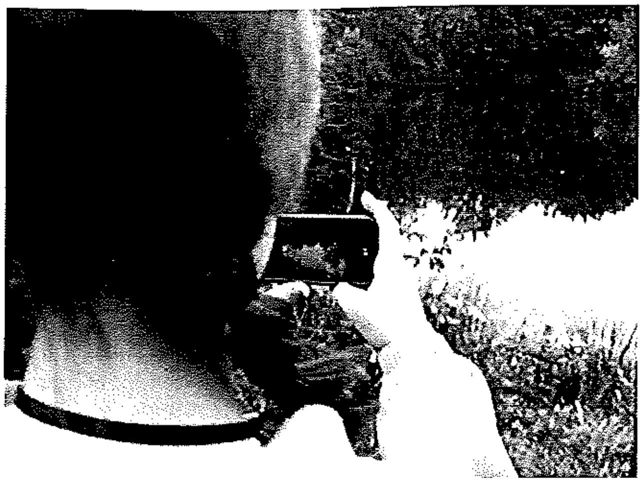

Fig. 59.1 Students collecting data

Fig. 59.2 Students analyzing data

ways and engage with realistic issues in a context with which the students are already connected" (Klopfer & Sheldon, 2010, p. 86). These two forms of AR (i.e., location-aware and vision-based) leverage several smartphone capabilities (i.e., GPS, camera, object recognition and tracking) to create "immersive" learning experiences within the physical environment, providing educators with a novel and potentially transformative tool for teaching and learning (Azuma et al., 2001; Dede, 2009; Johnson, Smith, Willis, Levine, & Haywood, 2011). Immersion is the subjective impression that one is participating in a comprehensive, realistic experience (Dede, 2009). Interactive media now enable various degrees of digital immersion. The more a virtual immersive experience is based on design strategies that combine actional, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is "inside" a digitally enhanced setting. Studies have shown that immersion in a digital environment can enhance education in at least three ways: by allowing multiple perspectives, situated learning, and transfer.

Furthermore, these two forms of AR both leverage the affordance of context sensitivity, which enables the mobile device to "know" where it is in the physical world and to present digital content to the user that is relevant to that location (Klopfer, Squire, & Jenkins, 2002). This review primarily focuses on location-aware AR played outdoors in the physical environment; while vision-based AR holds enormous potential for educators, there are few current studies on this version of AR. Research on related immersive media suggests ways in which vision-based AR could be powerful. For example, using the medium of sensorily immersive virtual reality, Project ScienceSpace contrasted egocentric rather than exocentric frames of reference (Salzman, Dede, Loftin, & Chen, 1999). The "exocentric" frame of reference provides a view of an object, space, or phenomenon from the outside, while the "egocentric" frame of reference provides a view from within the object, space, or phenomenon. The exocentric and the egocentric perspectives were found to have different strengths for learning, and the "bicentric" perspective alternating between egocentric and exocentric views was shown to be particularly powerful.

Theoretical Foundation for AR

The assertion that AR could provide enhanced learning experiences is grounded in two interdependent theoretical frameworks: (1) situated learning theory and (2) constructivist learning theory.

Situated learning theory posits that all learning takes place within a specific context and the quality of the learning is a result of interactions among the people, places, objects, processes, and culture within and relative to that given context (Brown, Collins, & Duguid, 1989). Within these contexts, learning is a co-constructed, participatory process in which all learners are "transformed through their actions and relations in the world" (Driscoll, 2000, p. 157). Situated learning builds upon and extends other learning theories such as social learning theory and social development theory, which posit that the level of learning is dependent upon the quality of the social interaction within the learning context (Bandura, 1977; Vygotsky, 1978).

Situated learning through immersive interfaces is important in part because of the crucial issue of transfer (Dede, 2008, 2009). Transfer is defined as the application of knowledge learned in one situation to another situation and is demonstrated if instruction on a learning task leads to improved performance on a transfer task, ideally a skilled performance in a real-world setting (Mestre, 2002). Researchers differentiate between two ways of measuring transfer: sequestered problem-solving and preparations for future learning

(Schwartz, Sears, & Bransford, 2005). Sequestered problem-solving tends to focus on direct applications that do not provide an opportunity for students to utilize resources in their environment (as they would in the real world); standardized tests are an example of this (Cobb, Yackel, & Wood, 1992). Giving students presentational instruction that demonstrates solving standard problems, then testing their ability to solve similar problems involves near-transfer: applying the knowledge learned in a situation to a similar context with somewhat different surface features.

When evaluation is based on the success of learning as a preparation for future learning, researchers measure transfer by focusing on extended performances where students "learn how to learn" in a rich environment and then solve related problems in real-world contexts. With conventional instruction and problem-solving, attaining preparation for future learning requires far-transfer: applying knowledge learned in a situation to a quite different context whose underlying semantics are associated, but distinct (Perkins & Salomon, 1992). One of the major criticisms of instruction today is the low rate of far-transfer generated by presentational instruction. Even students who excel in educational settings often are unable to apply what they have learned to similar real-world contexts. The potential advantage of immersive interfaces for situated learning is that their simulation of real-world problems and contexts means that students must attain only near-transfer to achieve preparation for future learning. Flight and surgical simulators demonstrate near-transfer of psychomotor skills from digital simulations to real-world settings; research on the extent to which AR can foster transfer is an important frontier for the field (Gallagher & Sullivan, 2011; Hays, Jacobs, Prince, & Salas, 1992).

Constructivist/Interpretivist theories of learning assume that meaning is imposed by the individual rather than existing in the world independently (Dede, 2008). People construct new knowledge and understandings based on what they already know and believe, which is shaped by their developmental level, their prior experiences, and their sociocultural background and context (Bruner, 1966; Vygotsky, 1978). Knowledge is embedded in the setting in which it is used; learning involves mastering authentic tasks in meaningful, realistic situations (Lave & Wenger, 1991). Learners build personal interpretations of reality based on experiences and interactions with others, creating novel and situation-specific understandings. Instructional design approaches based on Constructivist theories include anchored instruction (Cognition and Technology Group at Vanderbilt, 1993), case-based learning (Kolodner, 2001), cognitive flexibility theory (Spiro, Feltovich, Jackson, & Coulson, 1991), collaborative learning (Barron, 2000), microworlds and simulations (White, 1993), mindtools (Jonassen, 2005), and situated learning in communities of practice (Lave & Wenger, 1991).

Instruction can foster learning by providing rich, loosely structured experiences and guidance (such as apprenticeships, coaching, and mentoring) that encourage meaning-making without imposing a fixed set of knowledge and skills (Lave & Wenger, 1991). Constructivist learning theory outlines five conditions most likely to enhance learning: (1) Embed learning within relevant environments, (2) Make social negotiation integral to the learning experience, (3) Provide multiple perspectives and multiple modes of representation, (4) Provide self-directed and active learning opportunities, and (5) Support and facilitate metacognitive strategies within the experience (Bruner, 1966; Cunningham, 1992; Driscoll, 2000; Piaget, 1969; Vygotsky, 1978).

As a cognitive tool or pedagogical approach, AR aligns well with situated and constructivist learning theory as it positions the learner within a real-world physical and social context, while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation (Dunleavy, Dede, & Mitchell, 2009; Klopfer & Sheldon, 2010; Palincsar, 1998; Squire, 2010).

Augmented Reality Learning Research Teams and Experiences

Although AR has begun to gain popular attention over the last year (Johnson et al., 2011; Li, 2010), relatively few research and development teams are actively exploring how mobile, context-aware AR could be used to enhance K-20 teaching and learning. The majority of the findings presented in this review are studies from four research groups: (1) the MIT Scheller Teacher Education Program; (2) the Augmented Reality and Interactive Storytelling (ARIS) Group at the University of Wisconsin at Madison; (3) the immersive learning group at the Harvard Graduate School of Education; and (4) the Radford Outdoor Augmented Reality (ROAR) project at Radford University. While the majority of the findings presented in this review are drawn from these four labs, European teams (e.g., Futurelab, INVENTIO-project, Studierstube) are making significant contributions to the field as well, and their research was also incorporated in this review. Among all these research and development teams, they have developed and presented substantial findings on at least seventeen distinct AR experiences and simulations (Table 59.1).

All of these AR development teams are using some form of design-based research (DBR) approach to explore the feasibility and practicality of using AR in the K-12 environment for teaching and learning (Dieterle, Dede, & Schrier, 2007; Dunleavy & Simmons, 2011; Klopfer & Squire, 2008; Squire, 2010). DBR is a mixed methods approach that tests

Table 59.1 Augmented reality experiences

Name	Genre	Scenario
Science		
Outbreak at MIT	Inquiry-based simulation	Users investigate a disease outbreak and attempt to contain it (Design Team: MIT)
Environmental detectives	Inquiry-based simulation	Users investigate the source of a chemical spill to determine causal factors and environmental effects (Design Team: MIT)
TimeLab 2100	Inquiry-based simulation	Users travel back in time to change the devastating effects of climate change (Design Team: MIT)
Outbreak at RU	Inquiry-based simulation	Users investigate a disease outbreak and develop an antidote to stop it (Design Team: RU, NSF Grant: DRL-0822302) Web site:http://gameslab.radford.edu/ROAR/games/outbreak.html
Savannah	Inquiry-based simulation	Users explore the African savannah as a pride of lions to learn about the ecosystem and behavior of animals (Design Team: FutureLab). Web site: http://202.129.0.151/Teleport/FutureLab/savannah.htm
Gray anatomy	Inquiry-based simulation	Users investigate the causes behind why a whale has beached itself (Design Team: Harvard)
Mad City Mystery	Inquiry-based simulation	Users investigate a murder mystery involving environmental toxins (Design Team: UW-M)
Sick at South Beach	Inquiry-based simulation	Users investigate why a group of kids are sick after spending the day at the beach (Design Team: UW-M)
Lake Wingra	Inquiry-based simulation	Users explore the area around Lake Wingra to investigate if the lake is healthy (Design Team: UW-M)
EcoMobile	Inquiry-based simulation	Users explore a pond to determine the types of causal dynamics it exhibits (Design Team: Harvard, NSF Grant: DRL-1118530). Web site: http://ecomobile.gse.harvard.edu
History		
Dow day	Historical reenactment	Users "experience" a series of anti-Dow chemical protests that took place on the University of Wisconsin at Madison campus in October of 1967 (Design Team: UW-M). Web site: http://arisgames.org/featured/dow-day/
Greenbush	Inquiry-based simulation	Users explore a historic neighborhood to learn how urban planning impacts communities (Design Team: UW-M)
Buffalo hunt	Inquiry-based simulation	Users explore the American plains in the 1800s as an American Indian tribe to find buffalo herds (Design Team: RU). Web site: http://gameslab.radford.edu/ROAR/games/buffalo-hunt.html
Reliving the revolution	Inquiry-based simulation	Users explore the Lexington, MA revolutionary war battlefield to determine who fired the first shot (Design Team: Karen Schrier, MIT)
Museums and zoos		
Mobile augmented reality quest (MARQ)	Treasure hunt	Users worked in teams to solve puzzles related to the various museum exhibits (Design Team: Christian Doppler Laboratory). Web site: http://handheldar.icg.tugraz.at/marq.php
Zoo scene investigators	Inquiry-based simulation	Users explore the zoo to learn about the illegal wildlife trade (Design Team: MIT/Futurelab)
Other		
Hip Hop Tycoon	Inquiry-based economics simulation	Users attempt to set up a hip-hop store to sell music related merchandise in their neighborhoods (Design Team: UW-M)
Mentira	Inquiry-based language simulation	Users investigate a murder mystery requiring Spanish language skills (Design Team: University of New Mexico). Web site: http://www.mentira.org/
Alien contact!	Inquiry-based Math/English simulation	Users investigate an alien landing site to determine the intent of the extraterrestrial visitors (Design Team: Harvard). Web site: http://isites.harvard.edu/icb/icb.do?keyword=harp

and refines "educational designs based on theoretical principles derived from prior research" (Collins, Joseph, & Bielaczyc, 2004, p. 18). As applied to AR development, this formative research uses an approach of progressive refinement where AR designs that have been informed by learning theory frameworks as well as video game design principles (e.g., immersive narrative, role play, puzzles) are field tested in real world contexts with typical users to determine which design elements work well in practice and which elements need to be revised and retested (O'Shea, Dede, & Cherian, 2011). This iterative research and development process is similar to the rapid prototyping methods used in software engineering (Tripp & Bichelmeyer, 1990). Although DBR is challenging to conduct (Dede, 2004, 2005), it is the most appropriate approach to determine the design principles that leverage the affordances of this emergent and nascent pedagogical and technological tool, as well as insights about theory and heuristics about practical usage (Design-Based Research Collective, 2003; Squire, 2005).

K-20 Augmented Reality Literature Review

As a result of the DBR approach, the majority of the findings resulting from AR research and evaluation presented in this review pertain to the actual design of the units and how these designs are aligned with both theoretical constructs and unique AR affordances. Although the majority of the findings focus on design, we begin the review with unique affordances and limitations AR currently presents to educators, as well as the most frequently reported learner outcomes as found in the literature at this stage in AR's development.

Affordances

The most frequently reported affordance of AR is the ability to present to a group of learners multiple incomplete, yet complementary perspectives on a problem situated within a physical space (Dunleavy et al., 2009; Facer et al., 2004; Klopfer & Squire, 2008; Perry et al., 2008; Squire, 2010; Squire et al., 2007). This affordance is a direct result of the 1-to-1 device-to-student ratio provided within most AR learning environments, in which each student is interacting with a GPS-enabled device to participate in the activity. This unique affordance enables educators to incorporate collaborative pedagogical techniques and experience design approaches such as jigsaw and differentiated role play, which lend themselves well to inquiry-based activities requiring argumentation (Klopfer, 2008; Morrison et al., 2009; Squire, 2010).

By embedding these multiple perspectives within the environment and contextualizing them within a problem-based narrative, AR also affords educators the ability to leverage physical space as an additional layer of content for students to observe, manipulate and analyze (Perry et al., 2008; Squire et al., 2007). In other words, augmenting the physical environment with digital information transforms that environment into a venue for multiple, otherwise unrealized learning opportunities (Facer et al., 2004; Klopfer, 2008; Klopfer & Squire, 2008; Liestol, 2011; Morrison et al., 2009; Schmalstieg & Wagner, 2007; Squire et al., 2007).

The ability to access outside resources (i.e., Internet) and additional software on the devices to solve the given problem more effectively is another unique affordance of AR, which utilizes Wifi or data service-enabled handhelds (Klopfer & Squire, 2008). In addition, students may leverage the technologies provided by the handhelds in unanticipated, yet superior ways relative to how the designers had planned (e.g., using the video recording feature on the handheld to make video field notes instead of taking handwritten notes) (Perry et al., 2008).

Finally, across studies research reports that AR implementations result in substantial student motivation. As documented in the literature, student and teachers report high engagement as a result of using the handhelds, adopting roles, negotiating meaning within active, inquiry-based compelling narratives, solving authentic problems, and physically exercising (Dunleavy & Simmons, 2011; Dunleavy et al., 2009; Facer et al., 2004; Klopfer & Squire, 2008; Perry et al., 2008; Schmalstieg & Wagner, 2007; Squire, 2010; Squire et al., 2007).

Limitations

The most frequently reported limitation of AR in its current state of development is student cognitive overload. Across studies, researchers report that students are often overwhelmed with the complexity of the activities (Dunleavy et al., 2009), the scientific inquiry process and navigation (Klopfer & Squire, 2008), or making decisions as a team (Perry et al., 2008). Managing the level of complexity is a key instructional issue, and AR experience designers have attempted to decrease the cognitive load by: (1) creating an simplified experience structure initially and increasing complexity as the experience progresses (Perry et al., 2008); (2) scaffolding each experience explicitly at every step to achieve the desired experience/learning behavior (Klopfer & Squire, 2008); (3) limiting characters and items encountered by students to ~6 per hour (O'Shea, Mitchell, Johnston, & Dede, 2009); and (4) replacing text with subtitled audio (O'Shea et al., 2009; Perry et al., 2008).

Another limitation reported in the literature is the challenge of integrating and managing the overall AR experience from the designers' and teachers' perspectives. The first aspect of this limitation is cultural. The standards-driven efficiency culture and context of school systems are not well aligned with AR, which is best suited for exploratory, inquiry based activities. These are time consuming, more difficult to manage than presentational instruction, and focused on learning objectives (e.g., collaborative problem solving), which do not easily transfer to an achievement test (Clarke-Midura, Dede, & Norton, 2011; Facer et al., 2004; Klopfer & Squire, 2008). Difficulties such as these are comparable to the challenges classroom teachers face in conducting field trips.

The second aspect of this limitation is managerial. At this stage of development, AR integration necessitates a minimum of two to three facilitators to ensure proper implementation without any technical errors (Dunleavy & Simmons, 2011; Dunleavy et al., 2009). In addition, a successful AR implementation is highly dependent upon a skilled teacher to introduce and facilitate key points of the experience (O'Shea et al., 2009; Perry et al., 2008).

Finally, there are limitations with the current state of the art in location-aware and mobile technologies. Most of the technical problems experienced within AR implementations involve GPS error (Dunleavy et al., 2009; Facer et al., 2004; Perry et al., 2008). While GPS technology continues to evolve at a rapid pace, at present it simultaneously enables and limits AR implementations.

Although cognitive overload can be overcome with better design, and the evolution of the technology will remove the current technical challenges, the integration and managerial limitations detailed above present obstacles to the scalability of AR, comparable to the challenges faced by classroom teachers conducting field trips.

Design

The majority of the findings related to designing AR experiences, simulations and stories fall within four major categories: (1) location; (2) narrative; (3) roles; and (4) experience mechanics. While these findings are categorized for organizational and readability purposes, all of these areas overlap in various capacities and are interdependent (e.g., interplay among location, narrative and roles).

Location. The choice of venue or location is one of the most critical design decisions reported in the literature. As the use of the physical environment is a major aspect of the AR affordances, the choice of the location has multiple cascading effects on learning objectives, environment interaction, portability of the AR, and overall player experience.

There are two types of AR experiences in terms of location: (1) place-dependent and (2) place independent (Dunleavy, 2010; Klopfer, 2008; Squire et al., 2007). Place-dependent experiences are designed around a specific location and leverage the history, geography and physical structure of that location within the AR experience. These place dependent experiences are also referred to as highly localized (Klopfer, 2008), location-specific (Klopfer & Sheldon, 2010), and place-based (Squire, 2010). Place-independent experiences are designed to be highly portable and do not leverage any specific location; instead, they are designed to be used within any physical space that has sufficient size. These place-independent experiences are also referred to as lightly localized, space-based, and place-agnostic (Klopfer, 2008).

There are many pros and cons related to the choice between place-dependent and place-independent AR experiences, but the three major issues most frequently reported in the literature pertain to the authenticity of environment interaction and portability (Dunleavy, 2010; Klopfer, 2008; Squire et al., 2007). As AR is inherently a spatial medium, aligning the learning objectives with the potential interactions the users have with the surrounding environment is a critical factor to consider (Rosenbaum, Klopfer, & Perry, 2007). If authentic environmental observation and interaction are part of the learning objectives, then a place-dependent model is optimal, as the designers can scaffold experiences that require the users to observe and manipulate the physical environment (e.g., sampling water, observing topography, collecting leaf samples) to accomplish a specific experience-based task.

However, what is gained in authentic environmental interaction comes at a cost to the experience's portability and utility to other locations (Dunleavy, 2010; Klopfer, 2008). In other words, the more aligned an AR experience is to a specific environment, the less portable it is to other locations, which significantly decreases the experience's scalability. On the other end of the spectrum is a place-independent experience, which, once designed, is highly portable (i.e., can be played anywhere), but does not have a significant amount of authentic interaction with the environment (Klopfer & Sheldon, 2010).

Regardless of the choice of venue, AR experience development is a complex instructional design process, and this factor also needs to be considered when analyzing the trade-offs between place-dependent and place-independent models (Perry et al., 2008). These trade-offs are highly significant not only to specific experience design, but also to the field in general, so extensive research is needed to thoroughly explore this design dynamic (Dunleavy, 2010; Klopfer, 2008; Klopfer & Sheldon, 2010).

A related issue reported in the literature is the interaction between the location and the users' prior relationship with or perception of that location (Perry et al., 2008; Squire et al., 2007). One approach posited as an emerging best practice for AR design is to identify and design around *contested spaces* (Squire et al., 2007). By choosing a space that has a preexisting conflict or compelling narrative, the experience has a narrative "hook" and potentially gives the player more "agency" or sense of control within the experience (Squire et al., 2007). This approach also has the potential to make the AR experience and the location therein more meaningful by connecting the physical space with issues that are relevant to the lives of the users (Klopfer & Sheldon, 2010). Finally, choosing a location that students know conceptually or physically (e.g., a zoo) may provide familiar mental and physical models, thereby decreasing some of the inherent complexity and subsequent cognitive load for the participating users (Perry et al., 2008).

Narrative. The choice of narrative or story is another critical design decision reported in the literature. Similar to the choice of location, the choice of the driving narrative, which provides the structure and rationale for the AR experience, has a profound impact on the quality of the experience (Klopfer and Squire, 2008; Perry et al., 2008).

As previously discussed, designers can build AR experiences to facilitate interactive storytelling in which users need to collect pieces of a story (e.g., new stories, interviews, photographs, videos, etc.) distributed across and embedded within a physical environment. Designer must provide ways that users can subsequently construct these story "pieces" into a synthesized whole, to give the participants a complete view of the problem or narrative (Squire et al., 2007).

Similar to the spectrum possible within location choice, AR researchers report pros and cons of designing a fantastic narrative (e.g., being a pride of lions on the African Savannah) versus a lightly fictionalized narrative (e.g., being a scientist researching a chemical spill) (Facer et al., 2004; Klopfer & Squire, 2008). Facer et al. (2004) argue that the attempt to recreate a different physical reality (e.g., African savannah) on top of a real physical space (e.g., school playground) may be creating a potentially problematic disconnect between a highly fictionalized narrative and the real landscape. This assertion is reinforced within AR designs of authentic simulations, for which the objective is to "create games that could address important disciplinary practices in realistic ways" (Klopfer, 2008, p. 95).

Roles. As discussed above, one of AR's affordances is to present multiple incomplete, yet complimentary perspectives on a problem. This ability enables designers to create differentiated role-based AR experiences that use a combination of jigsaw pedagogy and interdependent roles to give students a complete picture of problem or experience space (Squire, 2010). According to Squire (2010), these fictionalized roles (1) invite students to apply preexisting personal experience to the problem solving process, (2) provide a context for argumentation, (3) create a sense of responsibility among the students who are "experts" in their domain, and (4) enable an active problem solver identity amongst students. In addition, the roles can be used to scaffold and model collaborative research roles, which closely approximate authentic scientific practices (Klopfer & Sheldon, 2010; Kamarainen et al., 2012; Rosenbaum et al., 2007; Squire & Jan, 2007; Squire et al., 2007). While the potential benefits of using role differentiation within AR experiences are clearly stated across the literature, several studies also emphasized the importance of explicitly designing and scaffolding this behavior within the experience (Perry et al., 2008; Squire & Jan, 2007).

Experience Mechanics. While the vast majority of the findings reported in the literature pertained to location, narrative and role, many other specific findings were also reported. These are categorized under experience mechanics, as most of them address particular strategies to enhance the AR experience design for teaching and learning.

The interplay between competition and collaboration is one of more frequently reported aspects of AR experience design. Across studies, researchers reported the need to structure the AR experience in a way that prevents the students' natural inclination to "race" through the experience in an effort to "beat" their classmates by being the first ones to finish (Dunleavy, 2010; Dunleavy et al., 2009; Klopfer and Squire, 2008). One specific solution was to design a nonlinear path with an entry point "gatekeeper" that triggered all the remaining digital objects that students needed to encounter (O'Shea et al., 2009). The students then choose their own paths and are therefore less likely to see themselves as ahead or behind their classmates.

Another experience mechanic finding reported in the literature is the tension between users focusing on the handheld and users interacting with their environment. Several studies documented the students becoming fixated on the handhelds rather than interacting with environment (Dunleavy & Simmons, 2011; Dunleavy et al., 2009; Perry et al., 2008; Squire, 2010). Designs should utilize the handheld to foster interaction with the context rather than to present extensive information independent of context.

Finally, the majority of AR designers have purposefully developed open-ended, inquiry-based experiences, which require argumentation, but do not have a closed "win state" or correct answer. Across studies, students reported that this design model was frustrating and that they desired to have a definitive answer rather than an open-ended scenario (Dunleavy et al., 2009; Klopfer & Squire, 2008; O'Shea et al., 2009; Squire, 2010). This is a challenge inherent in all forms of authentic inquiry-based instruction.

Development Platforms

All of the preceding affordances and limitations are dependent upon the available technology and the appropriate design. As the technology has evolved, so too have the tools developers have to design AR experiences to reach their educational objectives, as have the capabilities available to achieve a quality user experience. In our judgment, based on the current stage of devices, the state of the art in design, and educational objectives aligned with the affordances at present of AR, the ideal development platform would contain the following features:

- *Brower-based editor.* Designers create custom AR experiences using an editing Web site interface that enables them to embed an interactive layer of digital information into any outdoor physical location of their choosing without programming skills.

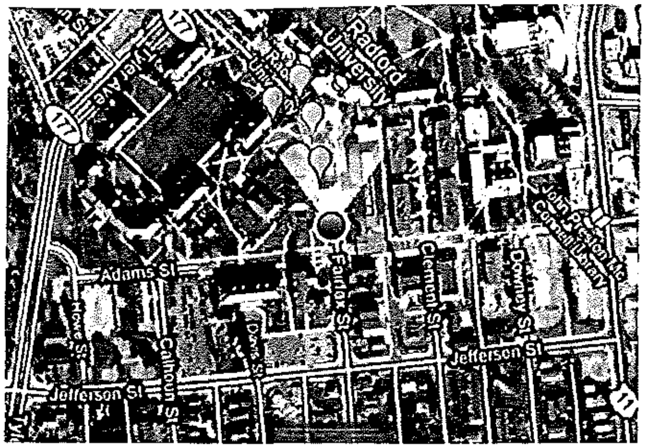

Fig. 59.3 Overhead view

Fig. 59.4 Live view

- *Digital Objects & Multimedia embedding (i.e., text, audio, graphics) (DO).* Designers can overlay the physical environment with interactive multimedia objects, items, and characters.
- *Location-based functions (i.e., GPS and compass) (LB).* App users trigger and experience location-specific narrative, navigation, and/or academic information when they come within relative proximity to the location.
- *Overhead and Live View.* App users toggle back and forth between an overhead, satellite view (e.g., Google Maps) and a live-view that uses the handheld's camera to display interactive media on top of the video image. The ability to use both will facilitate navigation (Overhead) (Fig. 59.3), immersion, (live-view), and authentic environment–player interaction (live-view) (Fig. 59.4).
- *User archive.* During the AR experience, App users have access via filter-driven archive or library to all digital objects they have encountered throughout experiences. This function allows participants to have on-demand access to all the information related to an AR experience, negating the need to remember the details or carry additional materials to record the information.
- *YouTube/Vimeo Embed.* Designers are able to embed YouTube or Vimeo videos into their AR experiences by simply copying and pasting the video's URL into the appropriate editor field. This enables designers to leverage all of the existing video content available on the YouTube and Vimeo libraries, thereby significantly reducing the media management and hosting requirements.
- *Roles.* Designers can assign and differentiate between different participant roles, enabling individualized and/or team-based experiences. This function mirrors popular video experience-based design elements in which each user has unique skills and information, thereby making that person valuable and necessary to team-based problem solving.
- *Dynamic Triggers.* Triggering and anti-triggering describe a feature whereby designers can enable and make visible digital objects in the AR environment, or disable and make invisible digital objects, dependent upon user input and/or movement. This allows for dynamic and cascading events within the AR experience.
- *Embedded Assessment.* Designers can embed assessments within their AR experience in multiple formats (e.g., alphanumeric keypads for fill in the blank and sentence completion, and multiple choice). The use of embedded assessments allows AR designers to more closely align their in-experience assessment to their educational objectives (e.g., learning about the Lincoln Memorial) while maintaining the immersive nature of the AR experience. Furthermore, the use of embedded assessments can provide a check on user comprehension, while also providing the experience designers with a control mechanism on user movement (Figs. 59.5 and 59.6).
- *Data Collection.* App users will be able to capture and store data during the AR experience. This data will include photos and audio, which can geo-tagged and stored either on the smartphone or the server. In addition, researchers could use this data collection function for assessment and evaluation purposes.
- *Device-to-Device Communication (D2D).* App users will experience a single shared AR world with other users, in which changes in one user's experience will generalize to other users' experiences. For example, if a user picks up a digital item within an experience, this item will disappear for all other users within the same experience.
- *QR Code Embed (QR).* Designers can embed QR codes into an AR experience to act as markers or targets for triggering various media (e.g., videos, Web sites, 3D models, etc.).
- *Vision-Based 3D Model Embed (3D).* Designers can embed vision-based or visual recognition AR to trigger interactive 3D models.

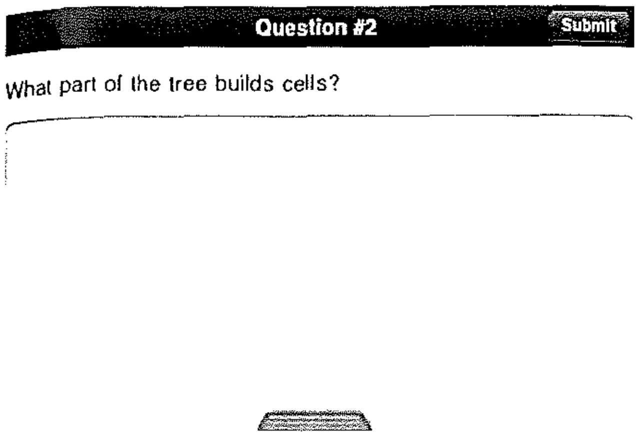

Fig. 59.5 Question prompt

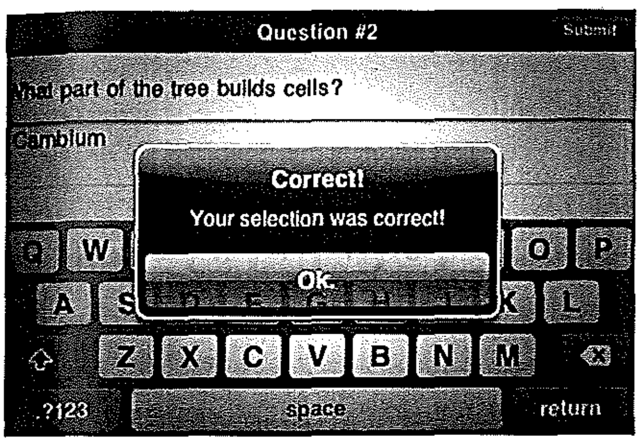

Fig. 59.6 Feedback

- *Social Networking* (*SN*). Designers can leverage social networking tools (e.g., Twitter, Facebook, Google +, etc.) as a mechanic within the AR experience or as a way to share content and/or AR experiences.

While there are several AR browsers (e.g., Layar, Junaio, Wikitude) and programming-based AR development tools (e.g., ARToolKit, ARchitect, metaio Mobile SDK) emerging across the field, there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR *without* programming skills. This is a key and fundamental requirement of any development platform that will be used by a diverse and often nontechnical audience of educators and instructional designers who nonetheless want to leverage the potential of AR in their students' learning environment. With this adoption and scaling requirement in mind, the following AR development tools provide the majority of the previously outlined functions while not requiring programming or server hosting from the user:

ARIS (http://arisgames.org/): is a "user-friendly, open-source platform for creating and playing mobile games, tours and interactive stories." ARIS was developed out of an ongoing research project from the University of Wisconsin at Madison's Game Learning and Society Group (Gagnon, 2010).

buildAR (http://buildar.com/): enables designers to embed Points of Interest (POIs) into the physical environment, to manage this content via their Content Management System (CMS), and to publish these experiences to the Layar and Junaio browsers.

FreshAiR (http://playfreshair.com/): enables designers to embed and experience a dynamic and interactive layer of digital information into any outdoor environment. FreshAiR was developed through a National Science Foundation (DRL-0822302) grant from Radford University's GAMeS Lab.

Hoppola Augmentation (http://www.hoppala-agency.com/): enables designers to create a layer of location-based content and publish this to Layar, Junaio and Wikitude.

TaleBlazer (http://education.mit.edu/projects/taleblazer): uses a visual block-based scripting platform to create interactive, location-based experiences. TaleBlazer was developed out of the MIT Scheller Teacher Education Program (STEP).

7Scenes (http://7scenes.com/): is a "mobile storytelling platform" that enables designers to create location-based experiences. 7Scenes was developed out of research from the Waag Society in The Netherlands.

Table 59.2 illustrates the availability of each function in AR development platforms as of January 4, 2012. The functions listed are not comprehensive and some of these platforms contain additional functions that do not fall within the listed categories. The reader is encouraged to explore each of these platforms to understand the complete range of functionality.

Conclusions

In 2012, approximately 197 million AR-capable phones will be shipped throughout the globe, doubling the amount shipped in 2010 (Gauntt, 2009). As this trend continues and AR-capable phones become more prevalent, instructional designers and educators will continue to leverage these devices to deliver instruction. While outlining some of the emerging practices in this effort, this review also documents the "idiosyncratic set of definitions, conceptual frameworks, and methods" inherent in a relatively recent and emergent field of study (Dede, 2011, p. 233). Due to the nascent and exploratory nature of AR, it is in many ways a solution looking for a problem. More accurately, AR is an instructional approach looking for the context where it will be the most effective tool amongst the collection of strategies available to educators.

Table 59.2 AR development platform function matrix (January 2012)

Function AR software	Browser-based editor	DO	LB	Overhead/ live-view	Archive	YouTube embed	Roles	Dynamic triggers	Assess	Data collect	D2D	QR	3D	SN
ARIS	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N
BuildAR	Y	Y	Y	Y	N	Y	N	N	N	N	N	Y	Y	N
FreshAiR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N
Hoppola	Y	Y	Y	Y	N	Y	N	N	N	N	N	Y	Y	Y
TaleBlazer	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	N	N
7Scenes	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y

Y yes, *N* no

The majority of the studies covered in this review use AR to replicate and guide the dynamic and complex nature of collaborative problem solving within a real physical environment. While the challenge of facilitating collaborative, experiential inquiry in and out of the classroom may be the best instructional problem solved by AR, researchers need to be continue exploring how this approach might ameliorate other persistent educational problems while also acknowledging its inevitable limitations within the expanding ecology of pedagogies.

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