Design Principles for Augmented Reality Learning

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Abstract

Augmented reality is an emerging technology that utilizes mobile, context-aware devices (e.g., smartphones, tablets) that enable participants to interact with digital information embedded within the physical environment. This overview of design principles focuses on specific strategies that instructional designers can use to develop AR learning experiences. A review of the literature reveals the following three design principles as instructive: 1. Enable and then challenge (challenge): 2. Drive by gamified story (fantasy); and 3. See the unseen (curiosity). These design principles can also be viewed as an attempt to either leverage the unique affordances of AR or minimize the limitations of the medium as reported in the literature (Dunleavy & Dede, 2014). As the field matures and more research teams explore the potential of AR to enhance teaching and learning, it will be critical to determine the design techniques that optimize the unique affordances of AR, minimize the limitations of the medium, and ultimately enhance learning across the curriculum.

Introduction

Augmented reality is an emerging technology that utilizes mobile, context-aware devices (e.g., smartphones, tablets) that enable participants to interact with digital information embedded within the physical environment. There are two forms of AR currently available to instructional designers: 1) location-based; and 2) vision-based. Location-based AR leverages GPS-enabled smartphones and tablets to present digital media to learners as they move through a physical area. The media (i.e., text, graphics, audio, video, 3D models) are triggered and oriented via GPS and compass technologies to augment the physical environment with narrative, navigation, and/or academic information relevant to the location. In contrast, vision-based or target-based AR presents digital media to learners after they point the camera in their mobile device at an object or target (e.g., QR code, 2D target).

These two forms of AR (i.e., location-based and vision-based) leverage several smartphone capabilities (i.e., GPS, compass, camera, object recognition and tracking) to create "immersive" and context sensitive learning experiences within the physical environment, providing instructional designers with a novel and potentially transformative tool for teaching and learning (Azuma, Baillot, Behringer, Feiner, Julier, & MacIntyre, 2001; Dede, 2009; Dunleavy & Dede, 2014; Johnson, Smith, Willis, Levine, & Haywood, 2011; Klopfer, Squire, and Jenkins, 2002).

This overview of design principles will focus on specific strategies that instructional designers can use to develop AR learning experiences. These principles are contextualized within specific AR games or experiences developed by the Radford Outdoor Augmented Reality (ROAR) project at Radford University (http://gameslab.radford.edu/ROAR/). A literature review recently published, *Augmented Reality Teaching and Learning*, provides more depth on many of these design issues at a conceptual level (see Dunleavy & Dede, 2014, p. 741-742). Based upon this literature review and my own research and development in this area, the following three design principles emerge as instructive:

1. Enable and then challenge (challenge)
2. Drive by gamified story (fantasy)
3. See the unseen (curiosity).

As seen in the parentheses, these principles loosely map onto Malone's (1981) key elements of intrinsically motivating instruction. These design principles can also be viewed as an attempt to either leverage the unique affordances of AR or minimize the limitations of the medium as reported in the literature (Dunleavy & Dede, 2014).

Design Principles

Enable and Then Challenge

One of the most frequently reported AR design challenges is preventing student cognitive overload during the experience (Dunleavy et al., 2009; Klopfer and Squire, 2008; Perry, Klopfer, Norton, Sutch, Sanford, & Facer, 2008). In a typical AR learning experience, students are required to simultaneously manipulate the mobile device, navigate to each location, interpret the content presented via the narrative, and collaboratively problem solve (Dunleavy et al., 2009). Therefore, using design strategies that *enable* learners to access and process the content and the activities within the AR experience, and *then challenge* them with higher-level problems is critical.

For example, in a science-based paleontology game called Dino Dig, an augmented reality game created using FreshAiR (http://www.playfreshair.com/) for the Institute for Creativity, Arts, and Technology (iCAT) and the Center for the Arts at Virginia Tech, players completed the following steps at each stage:

1. Navigate to location.
2. Receive paleontology or navigation information delivered through a narrative.
3. Learn about the physical adaptations of a different dinosaur at each stop.
4. Complete a challenge (e.g., work with partner, answer trivia question, etc.) requiring the application of the information presented in the previous step or information gleaned from observation and exploration of the campus.
5. Receive/unlock an accomplishment item, achievement, or badge (e.g., an egg from one of the dinosaur species, a piece of a dinosaur skeleton, a paleontology excavation tool, etc.)
6. Receive the location of the next hotspot.

While these steps are not seemingly onerous or burdensome for a player to complete, the complexity of completing these steps while navigating and processing content can be challenging. Therefore, it is critical for designers to intentionally guard against this overload to enable the student to successfully work towards the learning objectives. To accomplish this in Dino Dig, the designers used the following AR strategies that align with the enabling principle: 1) create a simplified experience structure initially and increase complexity as the experience progresses (Perry et al., 2008); 2) scaffold each experience explicitly at every step to achieve the desired experience/learning behavior (Klopfer and Squire, 2008); 3) replace text with audio (O'Shea, Mitchell, Johnston, & Dede, 2009; Perry et al., 2008); and 4) use videos containing narrators as "guides" that are the same age as the students (Dunleavy, 2013). In table 1 (see following page), the content from the first initial screens of the experience are notated to demonstrate how these principles are instantiated within the specific AR experience.

Although the main purpose of Dino Dig was to entertain, these same design principles of *enabling and then challenging* could be used in an AR experience with specific learning objectives. For example, in an AR experience designed to be played at the replica Powhatan Indian Village at the Jamestown Settlement (http://www.historyisfun.org/Powhatan-Village.htm) in Virginia, boys and girls are required to work in pairs to learn how the Powhatan Indians used natural resources in their everyday lives. This learning objective is directly aligned with the Virginia K-12 Standards of Learning (VS.1,

Table 1: EnablingAR learning.

Screen Content	Design Notes
Screen 1 (video): Welcome to Dino Dig, a mobile paleontology game where you become a scientist who collects the skeleton of the largest meat-eater ever to walk the earth– Tyrannosaurus Rex! My name is Ivy and I will be your guide and partner as we search this area for clues that will lead us to the bones. I need some help!  If you want to help me click 'Done' in the upper right hand corner.	All content is presented via video and the first screen/video introduces the players to the overall premise, and their role within the game. Narrator who acts as guide is the same-age as the targeted student demographic. Players are immediately asked to interact with mobile device to make a "choice" and told where to click to see the next screen.
Screen 2 (video): That is great. You are now my apprentice and we need to find those T-Rex bones before it is too late! At each spot, you will learn about a cool dinosaur and then I will ask you questions to ensure you are on the right track! If you answer each question correctly, you will find the T-Rex bones and become a true bone collector!! Now, click 'Done,' hold up your phone and look through it to find your next destination. It will look like a blue circle called, 'Newman Library." Find it and walk to it.	Players immediately assigned role and immersed in fantasy narrative. Players given structure of game activities and prior knowledge is activated with the reference to paleontology and collecting bones. The player is also instructed on the basic interface.

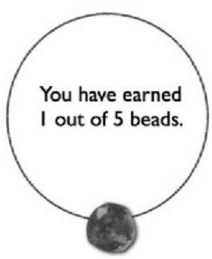
a, d, e, h, i; VS.2 c, e). As the two-person teams explore the replica village, they are prompted to observe and interact with the environment. They are also required to work collaboratively to find key information that is embedded digitally within the environment. As a result of the technology (1-to-1 device-to-student ratio) and the design, educators can use AR to present learners with incomplete, yet complementary perspectives on the same physical environment thereby incorporating and supporting collaborative pedagogical techniques such as differentiated role play, reciprocal teaching and other aspects of socio-cultural learning. This ability to scaffold and support positive interdependence to accomplish an objective situated within a physical space is the most frequently reported affordance of AR (Dunleavy, Dede, & Mitchell, 2009; Facer, Joiner, Stanton, Reid, Hull, and Kirk, 2004; Klopfer and Squire, 2008; Squire, 2010; Perry et al., 2008; Squire, Jan, Matthews, Wagler, Martin, Devane and Holden, 2007).

Drive by Gamified Story

The second design principle that aligns well with the affordances of AR is to drive the player interaction and learning through gamified stories or narratives. The story or narrative provides the structure and rationale for the AR experience, and it has a profound impact on the quality of the experience (Perry et al., 2008; Klopfer and Squire, 2008). AR enables instructional designers to create interactive stories where students collect and synthesize different pieces of information that are distributed across and embedded within the physical environment (Squire et al., 2007). By combining gamification elements, such as scoring systems or fail states, to an immersive narrative, the AR designer can leverage two of the most engaging elements of multiple genres (e.g., historical fiction, role-playing games) while also reinforcing the learning objectives.

For example, staying with the Powhatan Village AR game, we can see how these elements can be blended and leveraged to cross-fertilize

Table 2: Story and gamification

Student	Design Notes
Screen 1: Hi, my name is Henry Spelman. Were you guys sold to this village, too? Captain Smith sold me for some land about a year ago and I've learned how to do a lot of cool things like hunting, fishing and gardening. I've also kept a journal, which I can share with you if you think it would help. *Click 'Done' in the upper right hand corner to see the next screen.*	Henry Spelman was sold by Capt. Smith in 1609 to Powhatan for a village, which I am calling 'land' to limit confusion. Players are immediately told where to click to see the next screen.
Screen 2 (Assessment): Do you want Henry's help?	Immediately introduces interaction and the premise of dynamic, user-driven story.
Screen 3 Here you go. Whenever, you get stumped, look at the journal entries. The journal entries can be found in your Inventory in the Menu at the bottom of the screen. Now click 'Done' and go find the *Yehakin. Yehakin* is Algonquian for longhouse! Good luck.	Regardless of the answer, students receive the journal entries and are told where to find it in their inventory. "*I was carried By Capt Smith our Presidant to the Falls, to the little Powhatan where unknown to me he sold me to him for a town caled Powhatan and leaving me with him the little Powhatan*" (Spelman, 1872, p. 1) [original spelling maintained].
 Screen 4 Great job! You have earned the first bead of the Necklace of Truth - the Shelter Bead. Click 'Done' and press the play button the next screen to see an animation of the Yehakin construction.	The use of beads as a game mechanic that provides "endogenous value" or a scoring system (Schell, 2008, p. 32-33) is also historically accurate: "…adornments came in the form of large and small tube beads, tab pendants, trinkets, and geometic pendants or gorgets" (Woodward, 2005).

entertainment and education. During this experience, the players meet a non-playing character called Henry Spelman who acts as a guide and a resource as the students explore the replica village. In reality, Henry Spelman was an English boy who was either sold or given to the Powhatan or Paspahegh Indians in 1609 by Captain John Smith. Spelmen recorded his experiences in a journal, which was published in approximately 1872, and portions of this journal are embedded within the AR experience. The use of Spelman is not only historically accurate (http://historyisfun.org/cultural-intermediaries.htm) for the time period of the learning experience; it also provides an excellent vehicle for delivering critical information, driving the narrative, and recruiting identity (Gee, 2003). As the learners or players explore the village, they not only collect pieces of Spelman's journal, but they also earn "beads" for their necklace as a form of scoring. In table 2, screen content of the experience is notated to demonstrate how these principles are leveraged within the experience. You will also see some of the enabling principles discussed previoulsy, such as providing specific mobile device navigation cues.

Wolf Runner, an augmented reality running adventure game, is another example of using a gamified story to drive the player action. In this game, the player is presented with the following scenario:

Your small plane has crash-landed in the Canadian wilderness. Your only hope for survival is to collect supplies that are strewn across the forest floor and build a base camp in the plane wreckage until rescuers arrive. There is only one problem…

Figure 1: Wolf Runner in a suburban neighborhood.

you are in a frozen wilderness full of ravenous wolves! You must collect your supplies without being dragged down and devoured. To successfully do this, you need to run fast and collect supplies that will keep you alive. If you are too slow, you will die.

The design used in this running game combines timed intervals among supply caches with a compelling narrative where you are motivated to run with the fantastical threat of death by wolf. Unlike the previous examples, this AR experience could be played in any physical environment, such as a suburban neighborhood (See figure 1).

Similar approaches of gamifying and augmenting physical activity have been used in games such Zombies Run (https://www.zombiesrungame.com/) and the "relatively recent development of 'exergaming'or 'exertainment' products… signal a growing interest in combining children's interest in gaming with physical activity" (Dunleavy, Dede, & Mitchell, 2009, p. 20). With the ongoing obesity crisis, both in America and abroad, it may be possible to use AR and other mobile learning technologies in conjunction with other popular media and genres to address this growing health crisis.

See the Unseen

The third design principle that aligns well with AR affordances is the ability to make visible the otherwise invisible. Working in collaboration with School in the Park (http://schoolinthepark.net/), Qualcomm, and Radford University, the FreshAiR augmented reality development team (http://www.playfreshair.com/) created an interactive augmented reality experience located at the San Diego Zoo that leveraged both location-based and vision-based AR. The learning objectives included teaching the students about the anatomical features of the California Condor that helped the animal find and eat carcasses. Using FreshAiR, the students would be directed to the California Condor Exhibit at the zoo. Once there, the students would be prompted to point their mobile phones at a sign, which would in turn trigger a 3-dimensional model using Qualcomm's Vuforia (http://www.qualcomm.com/solutions/augmented-reality) technology. The combined technologies would then provide animated and interactive models to the students, which would change depending upon the student's distance from the sign. As illustrated in figure 2, if the student held the mobile device at different distances (e.g., 24, 16, 8 inches), the software would trigger a different model (e.g., panoramic scene, close-up of condor skull, anatomical cut-away of condor skull). The closer the students held the phone to the sign, the more detailed the model became, eventually culminating in an anatomical cutaway of the condor's skull revealing specific physical adaptions that are aligned with its food source (figure 2). In addition to the ROAR project, research and development teams such as the EcoMOBILE project (http://ecomobile.gse.harvard.edu/) at the Harvard Graduate School of Education are exploring how AR can provide "students a window into the unseen parts of the environment" to deepen their scientific understanding (Kamarainen, Metcalf, Grotzer, Brown, Mazzuca, Tutwiler, & Dede, 2013, p. 9).

In essence, the mobile device becomes a lens through which students can see elements of the environment that would otherwise remain hidden. The mobile device as a *lens rather than a screen* is a critical design metaphor as several studies have documented that students have the tendency to become fixated on the mobile device rather than observing the environment (Dunleavy et al., 2009, Dunleavy & Simmons, 2011; Perry et al., 2008; Squire, 2010). While location-based and vision-based AR can provide powerful and compelling experiences, it is critical that designers do not create experiences where the technology becomes a barrier to the environment. Rather the technology needs to drive the students deeper into the authentic observation and interaction with the environment and with each other if AR is to grow beyond a novelty technology. The use of AR to make visible the otherwise invisible as represented in this condor example is one possible approach that needs to be more fully explored.

Conclusion

The use of AR 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, and Mitchell, 2009; Klopfer and Sheldon, 2010; Palincsar, 1998; Squire, 2010). As a result, AR is well aligned with

Figure 2: Vision-based Augmented Reality

situated and constructivist learning theory as cognitive tool or pedagogical approach. While AR has the potential to enhance certain areas of learning, it is also important to remember that this is simply one tool among many that educators, designers and researchers need to investigate, and that it is not a tool well-aligned with all forms of effective instruction (e.g., repetition of a key skill set). As the field matures and more research teams explore the potential of AR to enhance teaching and learning, it will be critical to determine the design techniques that optimize the unique affordances of AR, minimize the limitations of the medium, and ultimately enhance learning across the curriculum.

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