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Camillia Matuk

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The Learning Affordances of Augmented Reality for Museum Exhibits on Human Health

CAMILLIA MATUK
New York University

Abstract: Augmented reality (AR) is an emerging technology with the potential to transform learning. By digitally adding or removing information from the physical world, AR creates a sense that real and virtual objects coexist, and can enhance people's interactions both with each other and with objects in the world. Most museum implementations of AR have been in the realms of art and history. Using examples from across formal and informal settings, this article illustrates the learning affordances of AR for museums that aim to communicate concepts related to human health. These topics often present spatiotemporal challenges for learning, but can be made more accessible to learners when contextualized within personally, socially, and culturally relevant contexts. After briefly reviewing research on learning with AR, the article examines how museum designers might leverage AR's capacity for spatial and temporal representation, narrative and interactivity, real-time personalized scaffolds, and collaboration, to create meaningful learning experiences on medicine and human biology. The article ends with a discussion of issues related to the use of AR in museums, and thoughts on future research.

Keywords: Augmented reality, Health, Learning, Museums, Review, Technology design

Insights from museum research highlight the importance of personalizing visitors' experiences, and of staying relevant in the face of changing knowledge (Selvakumar and Shugart 2015). These issues are especially important in communicating human health, a topic that has inherent personal relevance to visitors, and of which the underlying science is rapidly evolving.

Augmented Reality (AR) is an emerging technology with the potential to address issues of personalization and relevance in museum design. AR has been recently identified as one of several technologies likely to transform learning in both formal and informal settings, and to play increasingly important roles in

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professional, creative, and educational industries worldwide (Johnson et al. 2010, 2011, 2013). AR developed as a variation of virtual reality (VR) (Milgram et al. 1994). As with VR, AR can immerse a user in a digital environment, in which information is responsive to user's actions. However, while VR immerses users entirely in a virtual space, AR creates a sense that real and virtual objects coexist in the same space (Azuma 1997). Using a computer processor, sensors, input devices, and a display, AR mediates a person's sensory perception—including sight, smell, hearing, and touch—by virtually adding information to, or removing it from, the real world (Carmigniani et al. 2011).

While current examples of its applications are wide ranging, science museums have yet to explore the full potential of AR. Instead, exhibits on human health, biology, and medicine remain largely reliant on traditional media, such as text panels, video, or screen-based interactives.

This article discusses the learning affordances of AR for museum exhibits on human health. It first considers the significance of AR technology within current epistemological perspectives of museums. Then, through examples of existing AR applications, it discusses specific affordances of the technology and their alignment to characteristics of human health that are relevant to exhibit design. The article ends with a brief discussion of some implications and questions for future research that involves AR.

The Place of Augmented Reality in the Shift from Object-based to Visitor Experience Design

Dominating museum studies from the 19th century was an object-centered epistemology, by which real objects were considered to better communicate knowledge than is possibly by any representation of those objects (Conn 1998). Following this view, museums strove to encase the world's knowledge under glass, and designed exhibits with the intention of allowing objects to speak through their authenticity. Raised on pedestals and placed under spotlights, objects were showcased as centerpieces around which other materials were mere supplements.

Eventually, museum professionals came to embrace a more constructivist view of interpretation, which acknowledges the contribution of visitors' individual perspectives, prior knowledge. Objects, they realized, do not necessarily *contain* knowledge that is transmitted intact to visitors; rather, objects are one element in a system of building meaning making, which includes the conversations that objects generate during and after the museum visit. Although the earlier object-based epistemology persists to varying degrees in many contemporary museums, the focus in exhibit design has largely shifted toward more constructivist goals of supporting visitors' discourses (Evans, Mull, and Poling 2002).

Because AR mediates users' experiences of reality, heightening sensory perceptions, and enhancing interactions both with the physical world and with other people, it offers an opportunity for museum designers to enhance visitors' experiences with objects and with each other. By overlaying virtual information over ordinary physical objects, exhibit designers can intentionally prompt and guide productive discourse among visitors.

Technologies for Experiencing AR

The first AR technologies originated in the 1950s with cinematographer Morton Heilig's Sensorama (see Figure 1), a contraption that created a physically immersive theater experience through wide-angle stereoscopic 3D images, body tilting, wind, and aromas triggered at various points during the experience. (For brief histories of AR, see Agarwal and Thakur 2014 and Yuen et al. 2011.) Today, AR technologies fall into two broad categories: vision- and location-based. Vision-based AR adds details and interactivity triggered by static objects. For example, viewing a physical object (a paper, table, or wall) through a through a webcam or mobile device running an AR application will allow viewers to perceive overlaying digital information, such as sound, 3D objects and animations. These may be triggered by image recognition of quick response (QR) codes or 2D images (markers) displayed on the surface of those objects.

Location-based AR technologies include those that generate a series of events triggered by the user's location (Azuma 1997; Carmigniani et al. 2011). Using the location tracking capabilities of current mobile devices, these technologies allow users who are navigating real physical spaces to interact with, and have the world respond in ways that might occur in games or simulations.

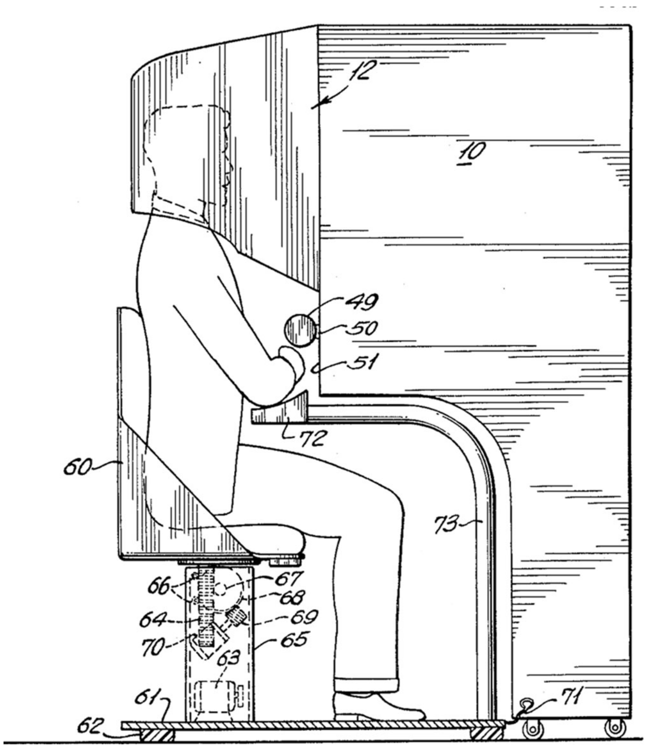

FIGURE 1 "Sensorama patent fig5" by Morton Heilig — Figure 5 of U.S. Patent #3050870 (via http://patft.uspto.gov/). Licensed under Public Domain via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:Sensorama_patent_fig5.png#/media/File:Sensorama_patent_fig5.png

Various available display techniques afford different ways of engaging with AR. Personal display monitors, such as contact lenses, glasses, and handhelds, allow individual exploration of augmented environments. Meanwhile, Spatial Augmented Reality (SAR) technologies, which overlay virtual information onto physical surfaces such as touch tables and wall projectors, enable joint experiences and collaboration among users.

AR is triggered by a user's location and head orientation, which are tracked by motion and location sensors such as gyroscopes, accelerometers, GPS, and solid-state compasses. AR information can also be triggered and manipulated through speech and gesture-based commands. Because most contemporary mobile devices have these sensor capabilities, visitors can bring their own smartphones or tablets to experience AR exhibits. Other examples of personal AR devices include Google Glass, Google's Tango Project, Microsoft's Hololens, and Google Cardboard.

Authoring Platforms

A number of AR authoring tools exist that cater to various levels of expertise. These include commercial, professional-grade platforms, such as Aurasma (aurasma.com), DAQRI (daqri.com), and Augthat (augthat.com); tools such as the AR GameBuilder (Klopfer and Sheldon 2010), which allow students to create their own AR experiences; and free platforms designed specifically for museum exhibit developers. For example, the Augmented Representation of Cultural Objects (ARCO) project offers authoring tools for easily creating interactive virtual 3D objects (Sylaiou et al. 2008, 2010; Wojciechowski et al. 2004), as does the ARToolKit (washington.edu/artoolkit), and the open source ARIEL Builder (https://code.google.com/p/ariel-builder), produced by The Franklin Institute and Patten Studio for the Augmented Reality for Interpretive and Experiential Learning project, which provides a visual programming environment for developing static AR exhibits.

Applications of AR

Because AR has the potential to heighten perceptions, enhance interaction, and increase and enhance productivity, its development has been pursued in entertainment, advertising, education and professional training across fields. Applications can be found in domains as diverse as archeology (Papagiannakis et al. 2005), construction (Churcher 2013), automotive (Couts 2011) (see Figure 2) and space navigation (Delgado et al. 1999), and music (Poupyrev et al. 2000); as well as in the medical practice, training, and rehabilitation sectors (John and Lim 2007; Nunes et al. 2014). With some exceptions, most museum-based applications of AR are in the realm of art, history, and cultural heritage.

Research on Learning with AR

Although AR has been actively developed for decades, most publications focus on detailing hardware or describing experimental prototypes. Attention to formal

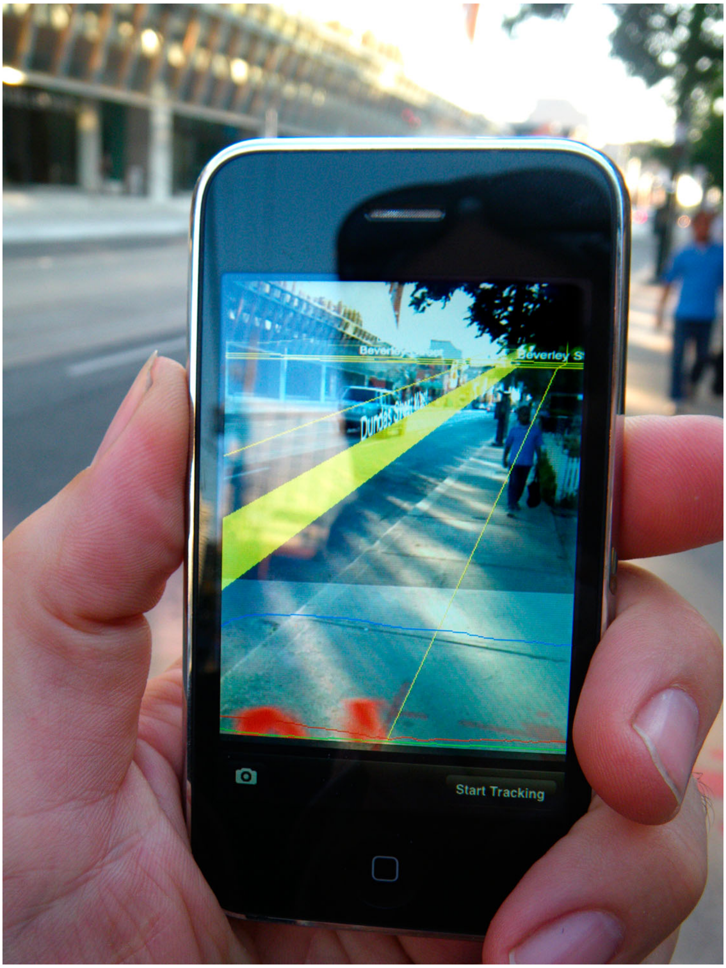

FIGURE 2 "MediatedReality on iPhone2009 07 13 21 33 39" by Glogger — Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:MediatedReality_on_iPhone2009_07_13_21_33_39.jpg#/media/File:MediatedReality_on_iPhone2009_07_13_21_33_39.jpg

evaluations of AR applications has been relatively recent (Dünser et al. 2008; Swan and Gabbard 2005), and mostly focused on issues of usability, user interest, and engagement, and less on issues of learning. Nevertheless, it has been suggested that AR has the potential to enhance learning and transform education (Nincarean et al. 2013; Johnson et al. 2010; Johnson, Adams and Witchey 2011; Wu et al. 2013).

Those who argue for the educational value of AR do so from the perspectives of situated learning (Lave and Wenger 1991), discovery-based learning (Bruner 1961) and experiential learning (Kolb 2014). These theories maintain that learning is grounded in action, and reliant on the interdependence of learners' physical, social, and psychological context (Greeno 1998; Sternberg and Pretz 2005). AR (which can enhance physical reality by creating social and collaborative contexts that are responsive to learners' actions, provide dynamic visualizations of otherwise invisible things, offer scaffolded interactions with real and virtual objects, and provide timely, personalized feedback) can support rich, situated learning experiences (Dunleavy and Dede 2014; Klopfer 2008; Klopfer and Squire 2008; Yoon and Wang 2014). In these manners, AR can potentially address many, if not all of the categories of impact outlined in the Framework for Evaluating Impacts of Informal Science Education Projects (Friedman 2008), including awareness or understanding, engagement or interest, attitudes, behavior, and skills related to STEM.

There is, for example, evidence that AR applications can motivate, engage, and support collaboration and conceptual understanding among learners. In one project, middle school students who took part in AR ecology field trips showed significant gains in content understanding as measured by pre- and post-tests; and deeper understanding compared to previous field trips that did not include AR, according to teachers' reports (Kamarainen et al. 2013). In one museum study, visitors to an AR exhibit on the physics behind magnetism demonstrated longer and more collaborative interactions than visitors without AR (Yoon and Wang 2014).

A possible disadvantage of AR, however, is the cognitive overload that users can experience through the additional information superimposed over an already information-rich world (Carpenter 2010). If anything, current research on AR in education demonstrates that, as with any other educational technology, learning —or failure to learn—does not occur solely by virtue of hardware and functionality, but largely by the design and implementation of a technology's applications. Design principles that emerge from educational applications of AR, in acknowledgement of this downside, attempt to reduce the cognitive overload that users can potentially experience. As synthesized by Dunleavy (2014), these principles include increasing the complexity of an AR experience gradually (Perry et al. 2008); providing explicit learning scaffolds at each step of the way (Klopfer and Squire 2008); avoiding text in favor of audio (O'Shea et al. 2009); and guiding experiences through AR using videos of narrators of similar age to the user (Dunleavy 2014).

Adhering to such pedagogically informed design principles may mean the difference between AR applications that are gimmicky and those that have educational value. Indeed, researchers have found that AR science exhibits can lead to greater learning gains among students, and attribute this effect to the exhibit's designed scaffolds (Yoon et al. 2012). Moreover, research on mobile AR guides in art museums addresses worries about the effects of information overload, finding instead that visitors can easily move between the real and digital environments without compromising the quality of their experiences or of their conceptual understanding (Damala et al. 2008).

The Affordances of AR for Communicating about Human Health

While diverse in content, topics in human health share certain notable qualities that, in combination, set them apart from other sciences. These include personal relevance, spatially and temporally complex relations between objects, and sociocultural and historical contexts. Each of these qualities is examined below in terms of the affordances of AR for spatial and temporal representation, narrative and interactivity, real-time personalized scaffolds, and collaboration. Examples from within and beyond the museum context will demonstrate how these affordances align with the goals of museums to design for personalization and relevance (Selvakumar and Shugart 2015).

Spatial and Temporal Representation

Understanding topics in the human sciences often requires sophisticated spatial and temporal reasoning. To appreciate physiological processes such as respiration, metabolism, and allergic reactions, for instance, one must be able to picture the gross and molecular anatomical relationships between structures and substances, and the complex causes and effects of their actions on one another. These relationships tend to not only be unfamiliar and invisible to most people, but also highly complex.

A feature of AR is its ability to represent real and virtual objects in terms of their spatial, temporal, and contextual relationships (Woods et al. 2004). One way of doing so is through virtual interactive 3D models displayed over static, flat surfaces. Looking through special visors, visitors of Imaginality Kiosks—marker-based AR kiosks on exhibit at New Zealand's Science Alive! and Australia's Science Works—can see interactive 3D animations of the movement of tectonic plates, volcano formation, eruption, and other earth processes (Woods et al. 2004).

Imaginality Unleashed is an extension of Imaginality Kiosks developed by the Human Interface Technology Laboratory New Zealand (hitlabnz.org) and commercialized by its corporate spin-off, MindSpace Solutions (mindspacesolutions.com). It provides tools for teachers and students to author their own marker-based AR learning materials, and includes a number of free modules, which allow learners to build and study 3D AR models of human organs, such as the heart; and the chemical structure of molecules (Maier et al. 2009). Similarly, mobile apps such as iSkull (see Figure 3) and DAQRI's free *Anatomy 4D* app (daqri.com/project/anatomy-4d), overlay explorable 3D models of the human body, skull, or heart over a printed page, allowing students of physiology and medicine to look through their handheld devices to study the complex spatial relationships of human anatomy.

Another AR approach to displaying spatiotemporal relations is through projection of virtual information over real 3D objects. For example, Virtual Showcases use mirror optics to project virtual information over physical museum artifacts (Bimber et al. 2001, 2006; Tanikawa et al. 2013). Similarly, several planetariums worldwide feature Science On a Sphere (SOS), a room-sized sphere upon which can be projected big data visualizations of such earth systems as ocean temperature, planetary weather maps, and climate change (NOAA 2016). In medical applications, live endoscopic video can be augmented with overlaying image-based information from previously probed tissue, thus allowing the tracking and mapping of biopsy sites during minimally invasive surgery (Mountney et al. 2009).

Narrative and Interactivity

Whether the topic concerns medicine, mental health, disease, physiology, or human evolution, the underlying science often has personal, emotional, historical, and

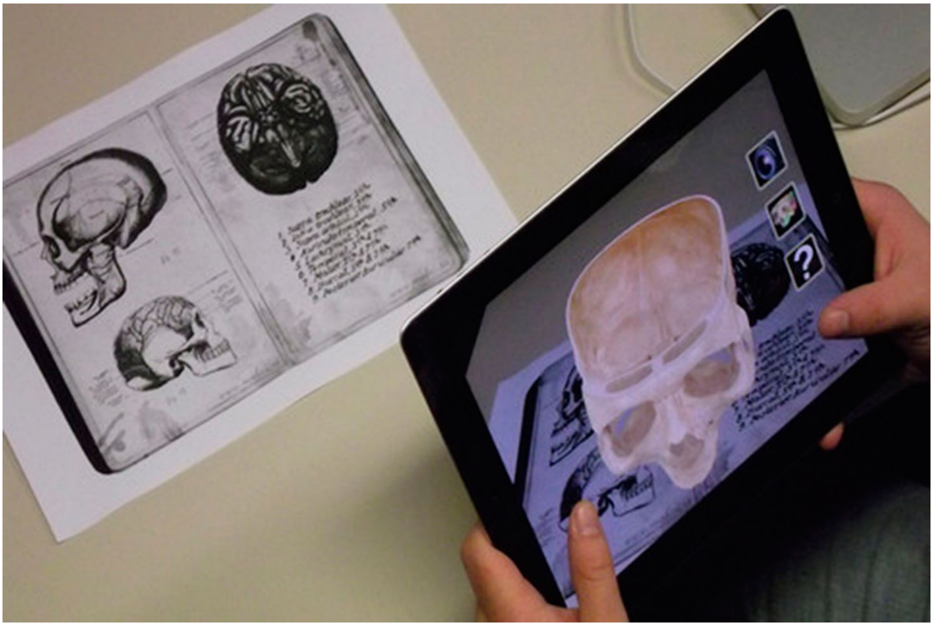

FIGURE 3 "App iSkull, an augmented human skull" by Hagustin. Licensed under CC BY-SA 3.0 via Wikimedia Commonss. https://commons.wikimedia.org/wiki/File:App_iSkull,_an_augmented_human_skull.jpg#/media/File:App_iSkull,_an_augmented_human_skull.jpg

sociocultural dimensions, which make them inherently interesting to visitors. Both questions and evidence regarding such issues as how the body works, the mechanisms of disease, and the neuroscience behind cognition and emotion, can derive from individual and collective experiences. Visitors will tend to have had personal experiences with, or else know friends or relatives affected by diseases such as cancer, HIV, and Alzheimer's. They may relate to the feelings of depression, or have experienced the effects of high blood pressure and heart disease. Visitors moreover face with daily decisions regarding their diet, sleep, and exercise.

Narrative is a powerful way to communicate health concepts. It has been used to effect behavioral change regarding personal health choices (Hinyard and Kreuter 2007), and is also a key tool in museum exhibit design (Roberts 2014). The Hall of Human Life at the Boston Museum, for example, uses video stories of local cancer survivors to convey personal experiences of living with disease (Cohn 2014); and the AIDS Museum (aidsmuseum.org) offers a stage for personal narrative through invited speakers and performance.

AR has the ability to create immersive and interactive narrative environments that can engage visitors with the content and enhance their learning (Klopfer and Squire 2007). The incorporation of virtual characters through video, graphics, and text can provide context to a story; and events triggered without the player's knowledge can increase anticipation and surprise (e.g., by a player's location or interaction with other players, or as a timed event).

Virtual storybooks such as eyeMagic (McKenzie and Darnell 2003) and MagicBook (now called SpellBound, getspellboundbooks.com) for example, allow readers to view through a handheld visor, overlays of 3D animated scenes on the pages of a book (Billinghurst et al. 2001). At the Ayala Museum, for example, visitors can look through rented visors at miniature wood carved scenes of notable historical events in Philippine history. These AR guides add visual and sound effects to both revive and animate the dioramas, which were first created in 1973 (ayalamuseum.org). Within Orlando Science Center's DinoDigs exhibit, a mixed reality system is used to simulate an ancient ocean scene over an existing traditional fossil display (Hughes et al. 2004).

Added interactivity can further allow visitors to engage with narrative. At the Hunt Museum in Limerick, Ireland, AR allows visitors to unlock information as they explore a replica of an historical room. On placing cards on a desk, which used RFID to recognize the card's shape and location, visitors trigger Flash animations to be displayed on a monitor embedded in a two-way mirror (Hall and Bannon 2006).

AR narratives can also help visitors make connections between, and build coherence among exhibits. Pervasive games are one example of the use of AR for these purposes. In contrast to mobile games, which are playable regardless of location, pervasive games take advantage of players' physical positions to stimulate gameplay. Pervasive games designed for museums include MIT's location-based treasure-hunt game, *Mystery at the Museum* (Klopfer et al. 2005), and *medien.welten* and *Expedition Schatzsuche* (Schmalstieg and Wagner 2007). In the latter two examples, teams of visitors navigate a museum with handheld devices, and are prompted to complete various tasks at different exhibits (e.g., taking pictures of objects, solving puzzles), which are connected within a broader narrative context.

Other examples exist beyond the museum context. For instance, the Ecosystems Mobile Outdoor Blended Immersive Learning Environment (EcoMOBILE) project is an AR field trip curriculum for middle school life science. Using mobile devices and probeware, students explore real ponds and forests, and are guided by information virtually embedded in the environment to make predictions, collect evidence, identify patterns, and solve ecological problems (Kamarainen et al. 2013).

Real-time, Personalized Scaffolds

Scaffolds can guide and support learning by encouraging reflective and metacognitive behaviors, and helping learners to make connections between new and existing ideas. Research finds that instructional scaffolds adapted to individuals' needs improves learning, both in formal classroom instruction (e.g., Black and Wiliam 1998; Gerard, Spitulnik, and Linn 2010; Herrenkohl, Tasker, and White 2011; Ruiz-Primo and Furtak 2007; van Zee and Minstrell 1997), and in informal learning settings, including ones that involve AR (e.g., Yoon et al. 2012).

Understanding the science of health, as with understanding other sciences, can be enhanced through such scaffolds. AR can scaffold learning, such as by prompting reflection, offering recommendations, and providing information of interest, that are personalized based on visitors' locations and actions. For example, Damala et al. (2008) developed a mobile museum guide that used geolocalization to enhance visitors' interaction and navigation through a fine arts museum in France. Mase, Kadobayashi, and Nakatsu (1996) describe Meta-Museum, an environment that leverages a museum's collections to engage visitors in personalized archeological investigations. Even as these tools deliver real-time, relevant information to visitors, they allow museums to gather visitor metrics and gain insight into visitors' preferences, and to determine which areas in the museum are more/less popular (e.g., iBeacons, McFarland 2014). Using these technologies can thus be a less expensive way to inform design refinements than hiring an evaluator.

In one recently funded project, The Exploratorium is exploring ways to use AR to guide visitors in making scientific observations (Yu et al. 2015). Overlaying visual cues and other supportive information will help visitors interpret real-time imagery of live specimens at the Microscope Imaging Station, an exhibit that features professional grade imaging technologies.

Collaboration

Learning in the health sciences, as with learning in other areas of science, can be supported by enriching the diversity of one's ideas through collaboration (Scardamalia 2002). Indeed, museum designers recognize the importance of not only encouraging visitors' interaction with artifacts, but also with other visitors (Selvakumar and Shugart 2015), and technology has been explored for encouraging productive visitor discourse. The Room of Opinions at Ireland's Hunt Museum, for instance, allows visitors to leave audio-recorded thoughts for other visitors to hear (Hall and Bannon 2006). A science center in Madison, Wisconsin similarly allows visitors to share their ideas with subsequent other visitors by leaving digital annotations on exhibits (Stevens and Martell 2003).

AR can likewise encourage discourse by offering a shared platform through which to relate personal experiences and to accomplish shared goals. Researchers developing AR for collaboration aim to either enhance typical face-to-face interactions, or enable a sense of co-presence among physical remote collaborators (Lukosch et al. 2015). Thus, AR may allow collaborators to, synchronously or asynchronously, create and annotate shared virtual or physical artifacts. For example, tourists may use a mobile AR app to embed and explore comments from previous tourists on visited landmarks, thus using virtual artifacts to engage in asynchronous discourse of physical locations (Bartie and MacKaness 2006).

Contrary to personal handheld devices, Spatial Augmented Reality (SAR) display systems allow multiple users to synchronously experience the same augmented reality. Examples of SARs include Studierstube ES (Schmalstieg and Wagner 2007), which allows users to share virtual workspaces through projections onto tables and walls, as well as through head-mounted displays; collaborative AR tabletop games, such as Shared Space (Billinghurst et al. 2000) and AquaGauntlet (Ohshima et al. 1999); as well as pervasive mobile-based games, such as *Environmental Detectives* (Klopfer and Squire 2007). The latter leads collaborative groups of students on investigations in the real world as they take on the roles of environmental engineers, sharing data they collect, and using artifacts they construct as objects for discussion.

There are multiple opportunities for collaborative learning with AR in the context of health. Visitors might engage with one another's ideas about the science, as through scientific investigations about genetic inheritance or evolution, for example. They might also come to deeper understandings through empathy by sharing one another's experiences with, for example disease and mental illness.

Issues with AR in Museums

Gimmickry

As developers explore the capabilities of rapidly evolving technologies, Hamilton (2012) notes that many innovations in AR are driven by commercial rather than educational goals. These can appear gimmicky and to lack staying power, perhaps as a reflection of how much more readily commercial industries will adopt and experiment with new technologies compared to educational ones. Museums in particular, which have traditionally emphasized the preservation and exhibition of established knowledge, tend to move more slowly relative to contemporary scientific and technological advances, as well as relative to visitors' expectations. It can be costly to experiment with new emerging technologies. Given the time and expense typically needed to develop new exhibits committing to using AR can seem risky, particularly when what is current today is likely to soon be upgraded, or obsolete.

Privacy Concerns

An often-noted concern about AR is with security and privacy (Roesner, Johno & Molnar 2014). Functionalities that enable AR, such as geotagging, location sharing, and face recognition, can lead users to feel loss of control over their personal information. Moreover, the value of certain data sharing applications can be contentious (e.g., intrusive advertising).

Privacy concerns are also issues in the museum context. For example, the DIY Augmented Reality project, AR experimenters Veenhof and Skwarek called on artists around the world to contribute pieces for virtual display within the existing exhibits of New York's MoMA (Sterling 2010). Visitors could see these virtual artworks, as well as a virtual 7th floor, by looking through their smartphones as they toured the galleries. That it was possible for artists unaffiliated with MoMA to develop and stage this AR exhibition without the museum's knowledge disrupts traditional loci of museum control and authority. At the same time, it demonstrates the accessibility of current AR technologies for both users and developers. As evidence of the positive outcomes that the accessibility of AR brings for generating new ideas and creations, MoMA has since adopted DIY Augmented Reality as a permanent exhibit.

Conclusions

Regardless of the technology used, the concept of AR is now well established. Its affordances, however, have yet to be fully explored in informal learning, and particularly with respect to communicating the health sciences. As illustrated above, AR has special affordances for spatial and temporal representation; narrative and interactivity, personalized scaffolding, and collaboration. These make AR suitable for communicating topics in human health, which not only have spatiotemporal challenges for learning, but also benefit from contextualization within personally, socially, and culturally relevant contexts.

As AR technologies continue to evolve, research will no doubt begin to move from a focus on usability to a focus on supporting conceptual learning. This paper highlights the significance—and the irony—of augmented reality experiences being designed by institutions whose business it has long been to preserve and communicate established knowledge through the authenticity of physical objects. In light of the epistemological shift from objects to discourses, the availability and accessibility of AR technologies challenges us to explore how AR in museums might help us engage more deeply, more meaningfully, and more authentically with what it means to be human.

ORCID

Matuk Camillia http://orcid.org/0000-0002-4067-1322

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