Augmented Reality in Education and Training

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Abstract

There are many different ways for people to be educated and trained with regard to specific information and skills they need. These methods include classroom lectures with textbooks, computers, handheld devices, and other electronic appliances. The choice of learning innovation is dependent on an individual's access to various technologies and the infrastructure environment of a person's surrounding. In a rapidly changing society where there is a great deal of available information and knowledge, adopting and applying information at the right time and right place is needed to main efficiency in both school and business settings. Augmented Reality (AR) is one technology that dramatically shifts the location and timing of education and training. This literature review research describes Augmented Reality (AR), how it applies to education and training, and the potential impact on the future of education.

Keywords: Augment Reality, Virtual Reality, Training, Educational Technology

Augmented Reality (AR) is a technology that allows computer-generated virtual imagery information to be overlaid onto a live direct or indirect real-world environment in real time (Azuma, 1997; Zhou, Duh, & Billinghurst, 2008). AR is different from Virtual Reality (VR) in that in VR people are expected to experience a computer-generated virtual environment. In AR, the environment is real, but extended with information and imagery from the system. In other words, AR bridges the gap between the real and the virtual in a seamless way (Chang, Morreale, & Medicherla, 2010).

According to Johnson, Levine, Smith, & Stone (2010), the history of AR goes back to the 1960s and the first system was used for both AR and VR. It used an optical see-through head-mounted display that was tracked by one of two different methods: a mechanical tracker and an ultrasonic tracker. Due to the limited processing power of computers at that time, only very simple wireframe drawings could be displayed in real time (Sutherland, 1968). Since then, AR has been put to use by a number of major companies for visualization, training, and other purposes. The term 'Augmented Reality' is attributed to former Boeing researcher Tom Caudell, who is believed to have coined the term in 1990.

According to Johnson, et al. (2010), AR systems can either be marker-based or markerless-based. Marker-based applications are comprised of three basic components which include a booklet for offering marker information, a gripper for getting information from the booklet and converting it to another type of data, and a cube for augmenting information into 3D-rendered information on a screen. On the other hand, markerless-based applications need a tracking system that involves GPS (Global Positioning System), a compass, and an image recognition device instead of the three elements of maker-based systems. Markerless applications have wider applicability because they function anywhere without the need for special labeling or supplemental reference points.

According to Chang, Morreale, and Medicherla (2010), several researchers have suggested that learners can strengthen their motivation for learning and enhance their educational realism-based practices with virtual and augmented reality. In spite of a great amount of research during the last two decades, adopting AR in education and training is still quite challenging because of issues with its integration with traditional learning methods, costs for the development and maintenance of the AR system, and general resistance to new technologies. Now that AR, however, has the promise to attract and inspire learners with exploring and controlling materials from a number of different perspectives that have not previously been taken into consideration, AR in education and training is believed to have a more streamlined approach with wider user adoption than ever before due to the improvement in computer and information technology. Kerawalla, et al. (2006) stated that even though many AR applications have been developed for educational and training purposes since the advent of AR in the late 1960s, its potential and pragmatic employment has just begun to be explored and utilized. He emphasized that AR has the potential to have learners more engaged and motivated in discovering resources and applying them to the real world from a variety of diverse perspectives that have never been implemented before.

How AR Works in Education and Training

Johnson, et al. (2010) stated, "AR has strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world." (p. 21). AR has been experimentally applied to both school and business environments, although not as much as classic methods of education and training during the last two decades. In addition to that, now that the technologies that make AR possible are much more powerful than ever before and compact enough to deliver AR experiences to not only corporate settings but also academic venues through personal computers and mobile devices, several educational approaches with AR technology are more feasible. Also, wireless mobile devices, such as smart phones, tablet PCs, and other electronic innovations, are increasingly ushering AR into the mobile space where applications offer a great deal of promise, especially in education and training.

AR in School

Professionals and researchers have striven to apply AR to classroom-based learning within subjects like chemistry, mathematics, biology, physics, astronomy, and other K-12 education or higher, and to adopt it into augmented books and student guides. However, Shelton (2002) estimated that AR has not been much adopted into academic settings due to little financial support from the government and lack of the awareness of needs for AR in academic settings.

AR in Business

In corporate venues, AR is a collaborative, skill-learning, explainable, and guidable tool for workers, managers, and customers. Also businesses have a better environment than those of educational settings regarding the ability to maintain the costs and support of AR applications. Many corporations are interested in employing AR for the design and the recognition of their products' physical parts. According to the evaluation of Shelton (2002), for example, enterprises not only may imagine designing a car in three dimensions in which they can make immediate changes when needed but also can create virtual comments that explain to the technicians what needs to be fixed.

The Current Position of AR in Education and Training

During the last few decades, many professionals and researchers have been developing pragmatic theories and applications for the adoption of AR into both academic and corporate settings. By virtue of those studies, some innovations of AR have been developed and are being used to enhance the education and training efficiency of students and employees. In addition to that, there are a great number of studies going on to improve the compatibility and applicability of AR into real life. However, according to Shelton & Hedley (2004), many questions still linger about its use in education and training, including issues of cost effectiveness, of efficiency between AR instructional systems and conventional methods, and the like.

AR in K-12 Settings

Freitas & Campos (2008) developed SMART (System of augmented reality for teaching) that is an educational system using AR technology. This system uses AR for teaching 2nd grade-level concepts, such as the means of transportation and types of animals. This system superimposes three dimensional models and prototypes, such

Figure 1.

A view of a student interacting with real objects (foam core card, table, wall) and artificial objects (Sun, Earth, annotations) through the augmented reality interface. This view is as would be seen if wearing an HMD (Shelton, 2002). Image by courtesy of Brett E. Shelton.

as a car, truck, and airplane, on the real time video feed shown to the whole class. Because most children spend a great deal of time playing digital games, game-based learning is one way to engage children in learning. Several experiments by Freitas & Campos (2008) were performed with 54 students in three different schools in Portugal. The results of a number of studies by Freitas & Campos (2008) indicated that SMART helps increase motivation among students, and it has a positive impact on the learning experiences of these students, especially among the less academically successful students.

AR in Higher Education

AR is a very efficient technology for both higher education such as universities and colleges. Students in both schools can improve their knowledge and skills, especially on complex theories or mechanisms of systems or machinery. For example, Liarokapis, et al. (2004) demonstrated that AR can make complicated mechanisms and difficult theories in higher education accepted and understood by students with contextually enriched interaction using AR technology. In the results of their research, Liarokapis, et al, (2004) showed an AR view of a student examining an augmented 3D model of a camshaft arrangement in conjunction with a set of real engine components.

The Application of AR in Different Subjects

Augmented astronomy. In an astronomy class, students learn about the relationship between the earth and the sun. For the sake of students' understanding, educators may employ AR technology with 3D rendered earth and sun shapes.

Shelton's (2002) study described the following:

> The virtual sun and earth are manipulated on a small hand-held platform that changes its orientation in coordination with the viewing perspective of the student. The student controls the angle of viewing in order to understand how unseen elements work in conjunction with those that were previously seen (p. 324).

In another example for the employment of AR in astronomy, Johnson, et al. (2010) described Google's SkyMap (http://www.youtube.com/watch?v=p6znyx0gjb4) as an application using AR technology. SkyMap overlays information about the stars and the constellations as users browse the sky with the see-through view from the camera on their smart phones (p. 23).

Augmented chemistry. Augmented chemistry is an interactive educational workbench that can show students how and what an atom or a molecule consists of via AR. Three elements, a booklet, a gripper, and a cube, are required to implement this task with both hands. Fjeld & Voegtli (2002) said that the booklet displays components by a printed picture and a name. One hand browses the booklet with a gripper that has a button used to connect an atom to the molecular model. According to Fjeld & Voegtli (2002), users first bring the gripper around the element in the booklet and get information about the element by clicking the button of the gripper. Users then move the gripper next to a cube, called a platform, which holds a molecule. Subsequently, by rotating a cube operated by the other hand, users can determine where and how the element connects to the molecule.

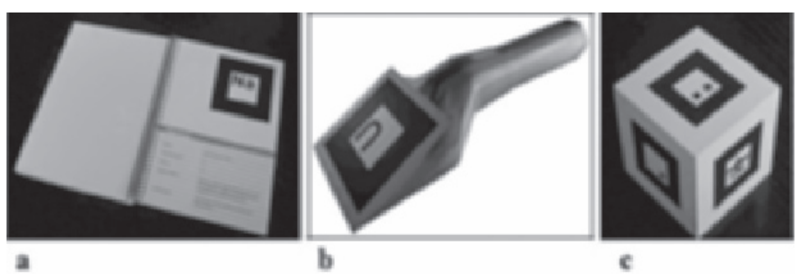

Figure 2.

a) Booklet offering one element per page – here Na – sodium. Each element is represented by a pattern. b) Gripper with a button (red) and a pattern. c) Cube with one distinct pattern for each surface (Fjeld & Voegtle, 2002). Image by courtesy of Morten Fjeld a Benedikt M. Voegtli.

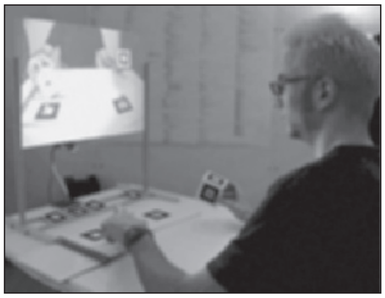

Figure 3.

System set-up with a typical situation of use: charging the Gripper with an element from the booklet (left). The platform (right) holds an unsaturated atom, with which a binding with the charged atom may be triggered (Fjeld & Voegtle, 2002). Image by courtesy of Morten Fjeld and Benedikt M. Voegtli.

Augmented biology. AR can be used to study the anatomy and structure of the body in biology. The Specialist Schools and Academies Trust (SSAT) demonstrated that teachers could use AR technology to show what organs of human beings consist of and how they look by watching 3D computer-generated models in the real classrooms. Moreover, students may be able to study humans' organs independently with their camera-embedded laptops and AR markers that connect PCs with AR information about biological structures of the human body (Retrieved from https://www.ssatrust.org.uk/achievement/future/Pages/Augmented-Reality.aspx).

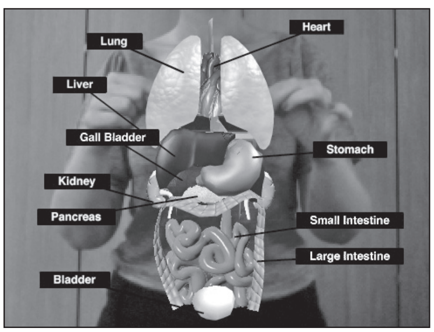

Figure 4.

A model of human beings' internal organs with AR technology that can be used in Biology class (Retrieved from http://www.ssatrust.org.uk/). Image by courtesy of The Schools Network.

Mathematics and geometry education. With AR technology, teachers and students can collaborate by interacting with each other for some issues on shapes or arrangements. According to Chang, Morreale, & Medicherla (2010), an AR application, called Construct3D, specifically was designed for mathematics and geometry education with three-dimensional geometric construction models (as cited in Kaufmann, 2006; Kaufmann & Schmalstieg, 2002; Kaufmann, Schmalstieg, & Wagner, 2000). This application allows multiple users, such as teachers and students, to share a virtual space collaboratively to construct geometric shapes by wearing head mounted displays that enable users to overlay computer-generated images onto the real world.

Furthermore, Kaufmann (2009) determined that AR can be used in dynamic differential geometry education in a wide range of ways. For instance, using the AR application, teachers and students can intuitively explore properties of interesting curves, surfaces, and other geometric shapes.

Physics education. Physics is another area where AR can also be used to demonstrate various kinematics properties. Duarte, Cardoso, and Lamounier Jr. (2005) evaluated AR to dynamically present an object that varies in time, such as velocity and acceleration. The real and estimated experimental results can be visualized by using AR techniques that are more interesting than existing learning methods, and thus improve learning. The research by Chae & Ko (2008) demonstrated that physics simulation is added to objects using open dynamics engine (ODE) library.

Figure 5.

Students working with construct3D inscribe a sphere in a cone (Kaufmann & Schmalstieg, 2002). Image by courtesy of Hannes Kaufmann

How AR is Applied to Books

A book can become "magic" by adding AR technology. Billinghurst (2001) determined that people, especially young children, can read books in more interactive and realistic ways by superimposing 3D rendered models onto books with AR technology. This is called "The MagicBook" which makes people's fantasies about becoming a part of the story a reality by using both a normal book and a handheld see-through AR device. People can turn the pages of a book, look at pictures, and read the text without any interactive assistance (figure 7a). However, if they look at the pages through a handheld AR display, they see three-dimensional models appearing out of the pages (figure 7b). The results of the research by Billinghurst (2001) demonstrated that with the MagicBook and the AR see-through device, people are able to see 3D scenes from any perspective simply by moving the AR device or the book. The Magic Book is an enhanced version of a traditional three-dimensional "pop-up" book. Moreover, Johnson, et al. (2010) described that augmented books can be developed into an AR edition after publication by installing special software, called AR tool kits, on users' computers and pointing an embedded camera of their PCs at the book to view computer-generated 3D models appeared out of the book.

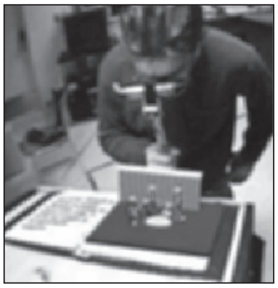

Image by courtesy of
Mark Billinghurst

Figure 6.

a) A book in reality. b) The MagicBook in AR. A man is using the MagicBook to move between Reality and Augmented Reality (Billinghurst, 2001).

How AR is Employed in Business Settings

AR technologies can be applied to a number of business settings, including tourism, museums, gaming, and industry.

Cultural Heritage Tour Guide

AR can be used as an interactive tool in cultural heritage sites by showing visitors the original images of the sites and informing travelers of historical episodes of the places with 3D effects. Vlahakis, et al, (2002) demonstrated on their research of ARCHEOGUIDE (Augmented Reality-based Cultural Heritage On-site GUIDE) that the AR tour assistant system provides on-site help and AR reconstructions of ancient ruins, based on users' position and orientation in the cultural site, and real time image rendering. ARCHEOGUIDE is based on computer and mobile technologies including AR, 3D-visualization, mobile computing, and multi-modal interaction techniques. The equipment consists of a Head-Mounted Display (HMD), an earphone and a mobile computing unit. But other versions include a PDA or a lightweight portable computer with a simple input device. With these AR devices, individuals can visit historic sites and tour around, both comparing an original image to an augmented modeling and viewing three-dimensional models of what the construction was, how it looked, and who the person was, even though it does not exist any more or just remains some ruins.

Industrial Maintenance

In the field of industrial maintenance, AR is a very practical assistance for staff in their highly demanding technical work. Henderson & Feiner (2009) observed that corporate sectors such as military, manufacturing, and other industries are the applied fields where AR competitively thrives and expands the scope of the technology itself. Particularly, according to their studies (Henderson & Feiner, 2009), which concentrate on the military sector, with the assistance of AR technology, military mechanical staff can conduct their routine maintenance tasks in a bulletproof vehicle more safely and conveniently. To do this, there are several required devices and apparatuses such as a tracked head-worn display to augment a mechanic's natural view with text, labels, arrows, and animated sequences designed to facilitate task comprehension, location, and execution.

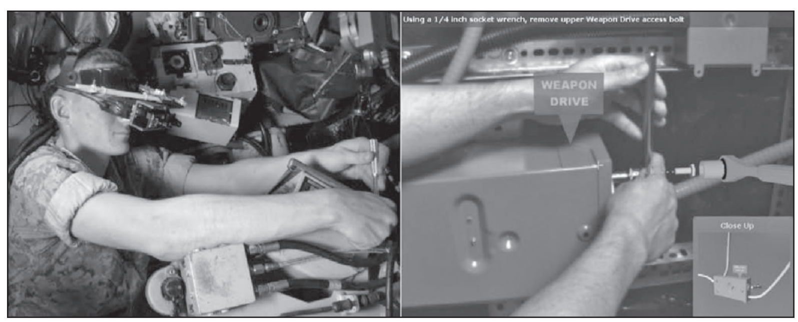

Figure 7.

a) A mechanic wearing a tracked head-worn display performs a maintenance task inside an LAV-25A1 armored personnel carrier. b) The AR condition in the study: A view through the head-worn display captured in a similar domain depicts information provided using augmented reality to assist the mechanic (Henderson & Feiner, 2009). Image by courtesy of Steven Henderson and Steven Feiner.

The same concept of the AR technology as the military maintenance works can be applied to manufacturing industries. A great deal of research in the field of AR has been paving the way for companies to employ AR technology in their own sectors. For instance, BMW, one of the famous German motor vehicle companies, has been interested in utilizing AR techniques in their car maintenance and repair divisions and developed an AR maintenance and repair system and data glasses (Retrieved from http://www.bmw.com/com/en/owners/service/augmented_reality_introduction_1.html). And they are just about to use contextually and interactively advanced AR technology as a means to support their service staff in their complex and technical work environments. According to BMW, technicians, wearing special data goggles and connecting to their computer servers, have all the information at their disposal, precisely where they need it: in the workplace, at the vehicle. By wearing AR glasses, for example, mechanics receive additional three-dimensional information on the part they are repairing to help them in diagnosing and solving the fault. Apart from the real environment, they see animated components about the part that needs replacing and the tools to be used, while an audio instruction talks to mechanics about each of the working steps through headphones integrated inside the goggles.

Museum Experiences

Another aspect of the employment of AR in corporate venues is museums. Museums are the places where hundreds of ancient and precious heritages are well preserved and displayed to visitors for the sake of their education. Kondo (2006) examined how AR technology can be applied to museum display systems. As an example, there are actual skeletons of dinosaurs in museums. Many visitors, mainly children, however, do not really know what a dinosaur looked like such as the shape of its body or its skin color. According to the research by Kondo (2006), individuals can see the recreated look of the dinosaur overlaid on the actual skeleton in this AR museum display system, which is primarily for children not only to have a better understanding of a dinosaur's appearance before but also to think scientifically.

AR in Gaming

AR Gaming is now particularly relevant to education and training in both academic and corporate venues. The Horizon Report (2010) said, "AR games that are based in the real world and augmented with networked data can give educators powerful new ways to show relationships and connections between the real life and the augmented reality." Johnson, et al. (2010) also demonstrated that one type of AR games includes a flat game board (map) that becomes a 3D rendered model with a mobile device or a webcam. This kind of game could easily be adopted by a variety of disciplines, including archaeology, anthropology, geography, and other subjects. K. L. Schrier (2005), for example, experimented with a role-playing game about history using AR technology. In her historic role-playing game with AR, participants are assigned to a specific historic role and spot and go to the real site to examine the role with a GPS-enabled handheld device, which shows the real site map with augmented information about the historic event relating to the role allotted. After completing a historic role-playing game, participants get items about the historic role and spot on the mobile display and come back to the classroom where they started, and then discuss what they have done and how they felt during the role-playing game. According to the results of her study, education and training via AR techniques, to a great extent, has 4 virtues. With this AR game, individuals can not only create an authentic practice field for solving problems and using real-world contexts and tools but also increase the potential for collaboration among participants, and enhance opportunities for reflection. Furthermore, AR games enable users to express new identities through role-playing and to encourage individuals to more profoundly explore a real site by interacting between the real and augmented world. Another approach to AR games enables users to create their own virtual people or objects, have them located in a specific place in the real world, and interact with them in real time to solve given problems.

Figure 8.

Students who participated in the history role-playing game "Reliving the Revolution" with AR technology (Schrier, 2005). Image by courtesy of Karen L. Schrier.

Conclusion

The future of AR as a visualization technology looks bright, as shown by the interest generated in business and industrial circles as well as discussed in popular periodicals and research papers in the education and training fields. Many questions still linger in terms of efficiency and when compared to traditional methods, particularly given the investments needed in research and design. However, there is much optimism of AR in education and training for the future. New technologies and information communications are not only powerful and compact enough to deliver AR experiences via personal computers and mobile devices but also well developed and sophisticated to combine real world with augmented information in interactively seamless ways.

The Future of AR in Education and Training

Several cutting-edge AR applications to date have been mostly developed for location-based information, social network services, and entertainment. New AR tools for other purposes such as education and training, however, will continue to be developed as the technology becomes more highly evolved and advanced than ever before. A considerable number of professionals and researchers from the field of education and training science predict that simple AR applications in education will be realized within a few years.

Interactive education. It is highly likely that AR can make educational environments more productive, pleasurable, and interactive than ever before. AR not only has the power to engage a learner in a variety of interactive ways that have never been possible before but also can provide each individual with one's unique discovery path with rich content from computer-generated three dimensional environments and models.

Simplicity. As shown in a great deal of previous research and professionals' opinions, AR could probably be focused on simplicity and ease of providing education and training experiences, so that learners can accept knowledge and skills with 3D simulations generated by computers and other electronic devices. In addition to that, related industries and technologies, such as computer and mobile industries, information and communication technologies, and Internet network infrastructures, including both wired and wireless services, possibly enable AR in education and training to be much more straightforward and succinct to approach and utilize than ever before.

Contextual information. In the view of many professionals and experts in the field of educational AR, it is possible that education and training-oriented AR can improve the extent and quality of information in both school and business settings by making education and training environments more educational, productive, and contextual. In this perspective, there seem to be many contextual elements possibly embedded in educational AR applications in order to enhance the quality of education and training by producing and delivering rich, constructive, and gainful content. For instance, Geo tag information for historical and cultural heritages could be connected as well as annotation regarding complex physical objects and artifacts could readily be added to AR tools in both business and school venues.

Efficiency and effectiveness. There is the potential that AR can promote the efficiency of education and training in academic and corporate surroundings by providing information at the right time and right place and offering rich content with computer-generated 3D imagery. AR may appeal to constructivist notions of education where students take control of their own learning and could provide opportunities for more authentic education and training styles. Besides, there are no real consequences if mistakes are made during skills training in terms of dangerous and hazardous work environments.

As the results of several studies have shown, AR systems can provide motivating, entertaining, and engaging environments conducive for learning. In addition, AR applications in educational settings are attractive, stimulating, and exciting for students and provide effective and efficient supports for the users.

AR keywords in the future. There are several keywords about AR in the future referred to by a large number of professionals and researchers in the field of AR in education and considered as the results of the developments of AR in the coming years. These include AR sensor and software technology for the standardization of existing mobile devices, growing power of mobile technology and devices, and the improvement of head-mounted displays and other AR hardware.

Future Works in Training with AR.

AR systems and applications have been developed and applied to many educational fields such as AR chemistry, biology, mathematics, and history in K-12 educations and mechanical engineering in higher education. On the other hand, relatively few studies have been done for the adoption and the usability of AR systems and innovations in industrial training. Both military training and manufacturing maintenance works are the only applicable areas of AR to date. However, as a number of professionals and researchers positively stated on the future possibility of AR in business sectors in their studies, AR in industrial venues has the potential for the expansion of its extent into other business areas such as manufacturing, services, government-related sections, and other industrial settings. Among them, there may be a good possibility that AR can be applied to occupational safety and health (OSH) sectors. AR could be adopted into safety inspection in power plants, chemical plants, and oil refineries, OSH education for managers and employees with computer-generated 3D environments, as well as AR games and simulations about hazardous materials handling.

Safety inspection with AR. There are no more important tasks than safety inspections, especially in power plants and oil refineries. Accidents that can happen in those factories might be more catastrophic and pernicious than anything else. Most safety supervisors and managers have been doing their duties in traditional ways, which include using paper-based checklists and on-site inspections on an offline-based scheduling. If AR technologies were applied to the safety inspections on power stations and oil refineries, the regular safety checkups may be more efficient and advanced than the conventional approaches. For example, safety directors put all information about a power plant, such as what it consists of, the history of inspection records, regular inspection schedules and other additional metadata of a power station, followed by creating the metadata markers of location and content about a power plant, which will be attached or posted on a certain building or title of a plant, to communicate with and be read by electronic handheld devices such as a smart phone and a tablet pc. Subsequently, when a safety manager inspects factories and equipment around a power station, a manager can see and know what is needed and what has been done at a certain factory by scanning a marker attached on the nameplate of a building with a smart phone. This safety inspection scenario, however, has some prerequisites about establishing an AR system and maintaining the consistency of the AR system, which need to be met beforehand. With solving these two issues, the safety inspection system using AR techniques might be worthy of the consideration as an alternative way to improve the time- and cost-efficiency of safety inspections.

Safety training with AR. In the same context as safety inspections employing AR, it might be a good idea that OSH training with the assistance of the AR technology can be enhanced in terms of rich content and empirical practices and might be improved in the aspect of the effectiveness of training for managers and workers. Whole changes on training materials and systems of industrial settings are definitely out of the question. However, some parts of industrial trainings could be alternated into three-dimensional content and environments generated by AR techniques. For instance, within an empirically enhanced AR work environment, that is more advanced and evolved than the virtual reality (VR) in the perspectives of graphics, versatility, and portability, users can experience real risks and potential hazards, which are sporadic and ubiquitous around any workplaces, by proactively discovering those dangerous situations in the real worksites with an AR goggle or other AR devices. This example especially belongs to dangerous and hazardous workplaces where an accident that could happen in the real world is considerably detrimental, harmful, and poisonous. When it comes to safety training materials, it is a definite possibility that AR technologies can make safety training media, such as booklets, posters, videos, and other content, much more productive and fruitful than ever before. By virtue of that rich training content with AR techniques, the owners of companies may boost the efficacy of safety trainings in their enterprises. In addition, the workers of corporations might uncomplicatedly accept their training skills and be aware of the degree of risks and hazards that may have been ignored and ambiguous before in their workplaces. Nonetheless, AR safety training materials have the same issues as the safety inspection, which are the developing and sustaining cost of AR content for safety drills in relating workplaces.

Future of safety consulting and training. As referred in this paper, it is a definite possibility that safety inspection and training are potential fields that AR technologies may be applied to and are almost the same as AR in education and other business settings is likely to be. However, it is certain that a few issues on developing and adopting AR systems in real educational settings should be answered in advance of the actual application and adoption. Those problems are how AR in education thrives in the real world and how AR systems and materials improve the effectiveness and efficiency of instruction in both corporate and academic venues. In conclusion, further studies are needed to examine solutions for the cost- and efficiency-related issues and to draw more attention from governmental and corporate settings with financial supports to AR in education and training.

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References

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments 6,* 4 (August 1997), 355-385. Cambridge, MA: The MIT Press.

Augmented reality. (n.d.). Retrieved from https://www.ssatrust.org.uk/achievement/future/pages/AugmentedReality.aspx

Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The Magic Book — Moving seamlessly between reality and virtuality. *IEEE Computers, Graphics and Applications, 21*(3), 2-4.

Billinghurst, M. (2002). Augmented reality in education. *New Horizons for Learning.* Retrieved from http://www.newhorizons.org/strategies/technology/billinghurst.htm

Chae, C., & Ko, K. (2008). Introduction of physics simulation in augmented reality. *ISUVR 2008 International Symposium on Ubiquitous Virtual Reality*, 37-40.

Chang, G., Morreale, P., & Medicherla, P. (2010). Applications of augmented reality systems in education. In D. Gibson & B. Dodge (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010,* 1380-1385. Chesapeake, VA: AACE.

Duarte, M., Cardoso, A., & Lamounier Jr., E. (2005). Using augmented reality for teaching physics. *WRA'2005 – II Workshop on Augmented Reality*, 1-4.

Dünser, A., Steinbügl, K., Kaufmann, H., & Glück, J. (2006). Virtual and augmented reality as spatial ability training tools. *Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on Computer-human interaction: design centered HCI*, 125-132. Christchurch, New Zealand.

Fjeld, M., & Voegtli, B. M. (2002). Augmented chemistry: an interactive educational workbench. *Proceedings of the international symposium on mixed and augmented reality (ISMAR '02)*. Darmstadt, Germany.

Freitas, R., & Campos, P. (2008). SMART: a System of augmented reality for teaching 2nd grade students. *Proceedings of the 22nd British Computer Society Conference on Human-Computer Interaction (HCI 2008)*, 27-30. Liverpool John Moores University, UK.

Henderson, J., & Feiner, S. (2009). Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR '09)*, 2009, 135-144.

Johnson, L., Levine, A., Smith, R., & Stone, S. (2010). Simple augmented reality. *The 2010 Horizon Report,* 21-24. Austin, TX: The New Media Consortium.

Kaufmann, H. (2009). Dynamic differential geometry in education. *Journal for Geometry and Graphics, 13*(2), 131-144.

Kaufmann, H., & Dünser, A. (2007). Summary of usability evaluations of an educational augmented reality application. *Second International Conference, ICVR 2007.* Beijing, China.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). Making it real: Exploring the potential of augmented reality for teaching primary school science. *Virtual Reality , 10*(3-4), 163-174. London, United Kingdom: Springer-Verlag London Ltd.

Kondo, T. (2006), Augmented learning environment using mixed reality technology, Proc. E-Learn, 83-88.

Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P., . . . Lister, P. (2004). Web3D and augmented reality to support engineering education. *World Transactions on Engineering and Technology Education, 2004 UICEE Vol. 3. No. 1.* Melbourne, Australia.

Schrier, K. L. (2005). Revolutionizing history education: using augmented reality games to teach histories. Master Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Shelton, B. E. (2002). Augmented reality and education: Current projects and the potential for classroom learning. *New Horizons for Learning.* Retrieved from http://www.newhorizons.org/strategies/technology/shelton.htm

Shelton, B. E., & Hedley, N. R. (2002). Using augmented reality for teaching Earth-Sun relationships to undergraduate geography students. *The First IEEE International Augmented Reality Toolkit Workshop.* Darmstadt, Germany.

Shelton, B. E., & Hedley, N. R. (2004). Exploring a cognitive basis for learning spatial relationships with augmented reality. Technology, Instruction, Cognition and Learning, 1(4), 323-357. Philadelphia, PA: Old City Publishing, Inc.

Sutherland, I. (1968). A head-mounted three-dimensional display. *Proceedings of Fall Joint Computer Conference, 1968*, 757-764.

Vlahakis, V., Ioannidis, N., Karigiannis, J., Tsotros, M., Gounaris, M., Almeida, L., . . . Christou, I. (2002). ARCHEOGUIDE: First results of an augmented reality, mobile computing system in cultural heritage sites. *Computer Graphics and Applications, IEEE,* 52-60.

Wichert, R. (2002). A mobile augmented reality environment for collaborative education and training. In M. Driscoll & T. Reeves (Eds.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2002,* 2386-2389. Chesapeake, VA: AACE.

Zhou, F., Duh, H. B. L., & Billinghurst, M. (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. *IEEE International Symposium on Mixed and Augmented Reality*, 15-18. Cambridge, UK.