© University Press 2024
ISSN 2719-6550
ISSN 2719-7417 online

"Journal of Education, Technology and Computer Science"
No. 5(35)/2024
www.eti.ur.edu.pl

Received: 30.09.2024
Accepted for printing: 11.12.2024
Published: 20.12.2024

DOI: 10.15584/jetacomps.2024.5.3

JULIÁNA LITECKÁ [1], **ZUZANA MITAĽOVÁ** [2]

AR Application Design Requirements for Technical Education

[1] ORCID: 0000-0002-1577-3140, Assistant Professor, University of Presov in Presov, Faculty of Humanities and Natural Sciences, Department of Physics, Mathematics and Technology, Slovak Republic
[2] ORCID: 0000-0002-2546-4640, Associate Professor, Technical university of Kosice, Faculty of Manufacturing Technologies with Seat in Presov, Slovak Republic

Abstract

We cannot question the importance of technical education at the present time. Each education has its own specifics, which must be considered during scientific and research activities. The paper deals with the AR application design in education. Within this contribution, we are based on the characteristics of augmented reality and the possibilities of developing applications for education, which relate to the Cognitive Theory of Multimedia Learning and our experience with the possibilities of creating applications in augmented reality. Based on this, in the contribution we defined five key areas (appearance, functionality, content, cognitive effectivity and sharing, compatibility and connectivity) of requirements for the design of AR applications with the specification of cognitive effectivity for technical education.

Keywords: augmented reality, technical education, AR application, design requirements

Introduction. Augmented reality in education

The first appearance of Augmented reality (AR) date back to the 1950s when Morton Heiling, a cinematographer, thought of cinema is an activity by taking in all the senses in an effective manner. In 1962, Heilig built a prototype of his vision which he described in 1955 in „The cinema of the Future" named Sensorama, which predated digital computing (Furth, 2011). Real prototype based on AR principle can be estimated around 1968 when Ivan Sutherland created the first head-mounted 3D display which projected a simple framed graphical view into a room (Pasaréti *et al.*, 2011).

Augmented Reality (AR) combines real-world environments with computer-generated objects, allowing users to naturally interact with overlaying three dimensional (3D) objects in the physical environment (Azuma, 1997). This technology is realized by application and device, which can possibly represent all information, as illustrated on Figure 1 on the left picture. Augmented reality technology integrates digital information with real environments in which people live. Everything is processed and produced in real time. This is one of the main differences with virtual reality, which uses artificial environments. Augmented reality uses the real world and completes it with digital information (Curcio, Dipace, Norlund, 2016). This technology is less developed largely because it needs even more processing power. It must interpret the real world and adhere to it all the digital information available to the system in question. This means processing a reality with infinite variables that change without a closed argument (Fernandez, 2017).

We also considered AR application that require removing real objects from the environment, which are more commonly called mediated or diminished reality (Azuma, 1997), in addition to adding virtual digital objects, Removing objects from the real world corresponds to covering the object with virtual information that matches the background to give the user the impression that the object is not there. Virtual objects added to the real environment show information to the user that the user cannot directly detect with his senses. This application is represented by a tablet device on Figure 1 on the right picture. Mixed reality combines real and virtual settings in various ways, to enable psychological immersion in a setting that blends physical and digital phenomena (Liu, Dede, Huang, Richards, 2017).

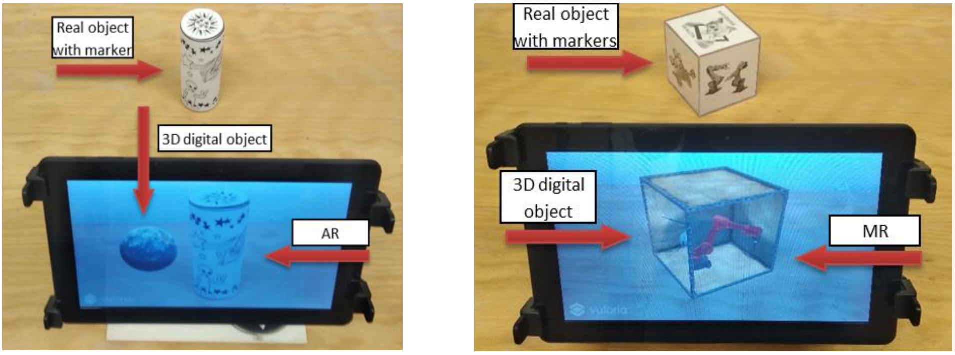

Figure 1. Augmented reality (left picture) and mixed reality (right picture) represented by tablet device

With the principle of Augmented Reality (AR), this space is enlarged even further. A virtual world co-exists with and is embedded in the physical world. Both worlds have their own full 3D existence in geometric and photometric properties and have dynamic evolvement over time. There are intricate relationships and exchanges between the two worlds in which one world adapts to, or influences, the other. The human user closes the interaction loop and generates a demand for understanding these relationships. The continuous flow, in which both worlds are viewed and manipulated, reaches a new quality of human–computer–physical–reality interaction. (Zlatanova, 2002)

Basic characteristic of augmented reality the Madden (2011) defined as:

– combines the real world with computer graphics,
– provides interaction with object in real-time,
– tracks object in real time,
– provides recognition of images or objects,
– provides real-time context or data.

From view of sciences researches of augmented reality for the last quarter of a century the results experienced a relatively large increase, which is also captured by several systematic review studies (Carmigniani, Furht, 2011; Dey, Billinghurst, Lindeman, Swan, 2018; Garzón, 2021) focused on research subject.

Based on the analysis of its evolution, (Garzón, 2021) pose three generations of AR applications in education. The first generation covers the period from 1995 to 2009 and could be described as hardware-based AR, as the delivery technology was the protagonist of the AR experience. The second generation covers the period from 2010 to 2019 and could be described as application-based AR, as the AR experience focused on AR applications rather than AR hardware. Finally, the third generation runs from 2020 onward and seems to be characterized by dedicated AR devices such as smartglasses and Web-based AR.

The popularity of augmented reality grew with the creation of applications for mobile devices (Madden, 2011) which became more accessible to the public, and with the development of the mobile game Pokémon Go™ (Garzón, 2021), which was of great interest to users. Pokémon Go™ is a mobile video game that requires real-world walking to “catch” augmented reality (AR) virtual creatures (Baranowski, Lyons, 2020). It has become increasingly accessible, affordable, and popular as advanced equipment is no longer required, which can be conveniently used on smartphones. Notably, the AR adoption in education has simultaneously increased, exhibiting potential in teaching and learning. The process creates an interactive visual learning form to provide a better learning experience. Thus, this idea allows educators to leverage the concept of interactive experience in an educational setting (Lam, Lim, Tan, 2023).

Teachers, engineers, researchers and practitioners are developing different tools and methodologies that include this technology, to benefit students and teachers by enriching the learning and teaching experiences. However, as reported by (Wu *et al.*, 2013), studies related to AR remain immature compared to studies of other technologies in education.

The analysis of the data in the systematic review (Garzón, 2021) does not show significant differences in effect sizes per level of education. Therefore, the results seem to indicate that the level of education does not moderate the impact of AR on education. However, it is necessary to consider that the number of studies in some levels of education is too low or inexistent. Advantages of using AR in educational settings go from psychological to learning aspects, learning gains continue to be the most reported advantage of AR systems in education followed by motivation. It is important to mention that each new study continues to report multiple benefits that help improve, not only the academic level of students, but also many other personality traits such as autonomy, creativity and collaboration. In addition, the fact that AR systems increase students' motivation and academic achievement could eventually reduce the costs associated with grade repetition and early school/college dropout, and the social problems that these events may cause. Despite the apparent multiple benefits that AR brings to education, this technology still has some difficulties to overcome, such as complexity, technical issues and some resistance from teachers.

In the technical or engineering education area we can find practical applications e. g. (Töröková, Török, Kočiško, Kaščak, 2020) and the possibilities of using extended and augmented reality applications in technical education for the preparation of future teachers (Korenova, Kožuchová, Dostál, Lavicza, 2019). When developing augmented reality applications, it is necessary to consider the specifics of each field of education so that the effectiveness of education reaches the required level. Therefore, it is necessary to pay attention to this issue.

The subject matter of the study. Requirements for AR application design for technical education

Augmented reality is based on a person's sensory perception of the physical world through digital equipment and digital content, which expands the real world with a virtual one. Therefore, how a person perceives such a mediated reality must be considered first when developing applications. From a user's perspective (Krüger, Buchholz, Bodemer, 2019) according to Azuma (1997) the technology that delivers the AR experience is characterized by three characteristics (examples are presented in Figure 2. a), b), c)):

1. Contextuality – this means that the user perceives the displayed virtual elements (e.g., objects, pictures, text) in the context of the real world around them (e.g., physical objects, other learners), with AR it is possible to situate learning in a relevant context, which may increase the authenticity and ground students in reality.

2. Interactivity – this entails that users experience the virtual elements reacting to their and other learners' actions. Because virtual objects in AR are placed inside the real world, they lend themselves to natural and intuitive inter-

action that is not possible with screen-bound virtual objects (e.g., "real" touching, gesture-based interaction). On the other hand, users can manipulate the virtual AR objects in other ways than purely physical objects (e.g., input of new data to change simulations, control through input devices) and can receive realistic and immediate feedback upon their input.

3. Spatiality – this means that the virtual elements should seem to exist in the same space as the real world. This represents a large part especially in the development of spatial imagination, which does not only mean understanding between 2D and 3D content, but also that elements are arranged in space.

For the process of acquiring knowledge to occur, it is not enough that these three characteristics are only perceived by the user, but they must be properly cognitively processed in relation to the set goals of education, that is, it must be clear what the user is to learn with the help of this technology. Therefore, it is important that the design of the application also considers cognitive load theory in relation to taxonomies of learning objectives. Cognitive Load Theory defines how the brain can only process selective incoming sensory data into working memory (Rudolph, 2017).

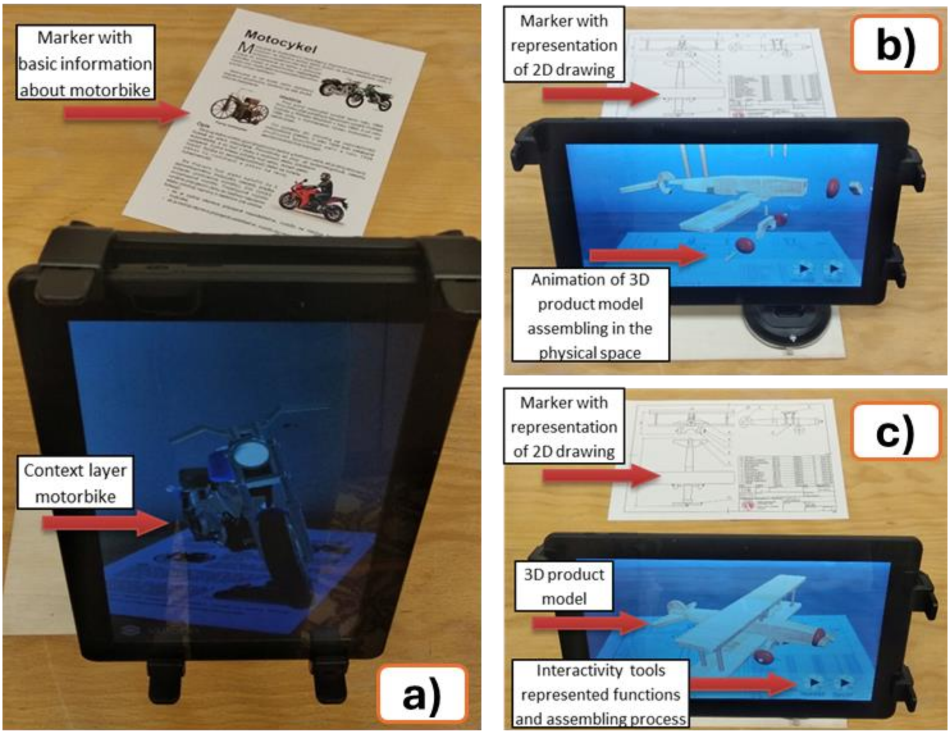

Figure 2. a) Contextuality, b) Interactivity, c) Spatiality of augmented reality

Research methodologies and tools

Based on the essence of the definition of AR, we can say that this technology, from the point of view of its digital content and its form of representation, falls into the category of multimedia applications, and we can classify it from the point of view of didactics as a multimedia didactic tool. In general, didactic principles must therefore be considered when designing an AR application. In the didactics of professional technical subjects, the explanation of these didactic principles has become established:

- principle of activity and awareness,
- the principle of purposefulness and education in teaching,
- the principle of science and adequate proportionality,
- the principle of connecting theory with practice, school with life,
- principle of visuality,
- principle of repeatability and sequence,
- the principle of the durability of knowledge and the all-round development of students' knowledge of abilities,
- the principle of collectivity in teaching and respect for the individual characteristics of students.

In multimedia learning the learner engages in three important cognitive processes. The first cognitive progress, selecting, is applied to incoming verbal information to yield a text base and is applied to incoming visual information to yield an image base. The second cognitive process, organizing, is applied to the word base to create a verbally based model of the to be explained system and is applied to the image base to create a visually based model of the to be explained system. Finally, the third process, integrating, occurs when the learner builds connections between corresponding events (or states or parts) in the verbally based model and the visually based model. (Mayer, Moreno, 1998) In order to effectively engage the learner in the learning process, designers developing an AR application should balance the use of visual and verbal information. In this area Mayer (2002) developed Cognitive Theory of Multimedia Learning and has spent almost three decades researching and updating this theory as instructional multimedia has evolved, which were based on 12 principles of multimedia design (Rudolph, 2017).

Development (analysis of research results)

Augmented reality is a very young industry, and there are still no generally accepted standards for developing AR applications (Ablyaev, Abliakimova, Seidametova, 2020). Based on our experience with the use of existing applications, our own development of AR applications for mobile devices, research of creating possibility such applications by the game engine Unity and Vuforia, and a theoretical study based on the sources used in this document, we have established the following 5 areas of requirements for the design of AR applications considering technical education needs.

1. *Appearance*

The application should have a visually attractive, clear and intuitive graphic interface, in which the control elements are clearly identifiable, grouped into logical groups and subgroups, so that the spatial contiguity principle is preserved (Mayer, 2002). The interface should be created in a responsive design so that the graphic resolution of the controls and content is maintained on different screen sizes and is sufficiently readable. The interface should not interfere or overlap the content itself. 3D content should have a realistic appearance, not only in shape similarity, but appropriate materials, textures, shaders, effects, particle systems should be used, which approximate the image of the virtual world as closely as possible to the physical one.

2. *Functionality*

Depending on the complexity of the application, it is necessary to consider what will be the concept, and the model of the application used (Amory, Seagram, 2003). It is important that the sequence of steps leads to the acquisition of a certain cognitive level of knowledge, e.g. memorization, understanding, application, analysis, evaluation or creativity. The application should have an action guide created, for example in the form of pop-up windows, navigation or an avatar, so that the user can consistently navigate through the content and select controls. The main functionality should be active interactivity, which means that the user should receive feedback through his actions, for example in the form of a simulation, a pop-up window with an evaluation of the correctness of the solution, the possibility of sharing the result and receiving feedback from the wider public, the possibility of verifying whether his solution in the real world is in harmony with the virtual and so on.

3. *Content*

Only the display of 3D content without additional contextual information such as text, animation or the possibility of manipulation cannot be considered to be in accordance with the principle of multimedia (Mayer, 2002). For example, only a static display of a machine, where it is not clear what kind of machine it is or what its activity is, does not lead to the acquisition of knowledge, as the user cannot cognitively evaluate what is the subject of the displayed information. In the case of AR applications, the carrier of contextuality can be either a marker or virtual content. For an easier understanding of the phenomena, it is not necessary, in accordance with the principle of coherence (Mayer, 2002), that a lot of details be present, for example, to illustrate the principle of the operation of the machine, it is not necessary to display all parts of the machine, but only those that basically present the principle of its functionality, or it is possible to separate these parts from the whole.

4. *Cognitive effectivity*

The application should be created in such a way that the cognitive level of the set goals can be clearly demonstrated, measured and controlled. Applications that do not have a clear educational goal cannot be considered educational applications. Applications should be researchable before their introduction and demonstrable cognitive effectiveness in relation to conventional didactic means. In relation to technical subjects, the cognitive effectiveness of AR applications should be aimed at:

– the acquisition of terminological concepts of parts of technical machines, devices and tools,

– the reading and creating technical visualization and drawing documentation,

– the choice of technological procedures, tools, tools for manufacturing products,

– the understanding how simple and complex technical principles work,

– the manipulation and operation with machines, devices and tools,

– the own design of technical solutions and innovations.

5. *Sharing, compatibility and connectivity*

The availability of AR applications is a key aspect for their introduction into education. A user who does not know how to access AR applications, whose device is not compatible with the platform for which the application was created or does not have access to its content cannot learn. Therefore, a necessary requirement for the creation of such applications is that they are available for the widest possible spectrum of devices and their platforms. At the same time, these applications should have a more complex character, so that a lot of micro-applications are not produced. The size of the data and the performance requirements of data processing equipment are also related to the complexity of the solutions. Therefore, it appears to be the most appropriate form of creating Web-based AR applications (Qiao *et al.*, 2019).

Conclusions

To organize and organize the conditions of the educational process in the fulfilment of the educational curriculum, the teacher should have the opportunity to choose suitable didactic resources to ensure the effectiveness of the educational process. Through our testing of the possibility of creating applications in augmented reality and the study of available scientific and research resources, we found that these possibilities to creation of AR applications are almost unlimited, respectively the limitations are connected with the price and availability of technical equipment and software solutions for the creation of AR applications, the time required to create such an application and skills (3D modelling, programming, graphic processing, creation of animations and effects…) to create these applications. Without a didactic approach and respect for scientific research results in the field of cognitive acquisition of knowledge, the application cannot effectively fulfil the function of a didactic tool. Our intention was therefore through this contribution to determine 5 areas of key requirements for the creation of educational AR applications with the definition of the area of cognitive efficiency within technical education.

Acknowledgements

The contribution was created with the support of the project VEGA 1/0055/24 Výskum špecifických schopností a zručností pre čítanie s porozumením v predmete technika zohľadňujúci súvislosť s úrovňou geometrickej, respektíve priestorovej predstavivosti žiakov základnej školy.

References

Ablyaev, M.R., Abliakimova, A.N., Seidametova, Z.S. (2020). Criteria of evaluating augmented reality applications. *Advanced Engineering Research, 20*(4), 414–421.

Amory, A., Seagram, R. (2003). Educational game models: conceptualization and evaluation: the practice of higher education. *South African Journal of Higher Education, 17*(2), 206–217.

Azuma, R. (1997). A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environment*s, *6*(4), 355–385.

Baranowski, T., Lyons, E.J. (2020). Scoping Review of Pokémon Go: Comprehensive Assessment of Augmented Reality for Physical Activity Change. *Games for Health Journal, 9*(2), 71–84.

Carmigniani, J., Furht, B. (2011). Augmented reality: an overview. In: *Handbook of augmented reality* (pp. 3–46).

Curcio, I.D.D., Dipace, A., Norlund, A. (2016). Virtual realities and education. *Research on Education and Media, 8*(2), 60–68.

Dey, A., Billinghurst, M., Lindeman, R.W., Swan, J.E. (2018). A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. *Frontiers in Robotics and AI, 5*, 37.

Fernandez, M. (2017). Augmented virtual reality: How to improve education systems. *Higher Learning Research Communications, 7*(1), 1–15.

Furht, B. (ed.) (2011). *Handbook of augmented reality*. Springer Science & Business Media.

Garzón, J. (2021). An Overview of Twenty-Five Years of Augmented Reality in Education. *Multimodal Technologies and Interaction*, *37*(7).

Korenova, L., Kožuchová, M., Dostál, J., Lavicza, Z. (2019). Applications of Augmented Reality Apps in Teaching Technical Skills Courses. In: *Augmented Reality in Educational Settings* (pp. 383–409). Leiden, The Netherlands: Brill.

Krüger, J.M., Buchholz, A., Bodemer, D. (2019, December). Augmented reality in education: Three unique characteristics from a user's perspective. In *Proc. 27th Int. Conf. on Comput. in Educ* (pp. 412–422).

Lam, M.C., Lim, S.M., Tan, S.Y. (2023). User Evaluation on a Mobile Augmented Reality Game-based Application as a Learning Tool for Biology. *TEM Journal*, *12*(1).

Liu, D., Dede, C., Huang, R., Richards, J. (eds.) (2017). *Virtual, augmented, and mixed realities in education*. Singapore: Springer.

Madden, L. (2011). *Professional augmented reality browsers for smartphones: programming for junaio, layar and wikitude*. John Wiley & Sons.

Mayer, R.E. (2002). Cognitive theory and the design of multimedia instruction: an example of the two-way street between cognition and instruction. *New Directions for Teaching and Learning, 89*, 55–71.

Mayer, R.E., Moreno, R. (1998). A cognitive theory of multimedia learning: Implications for design principles. *Journal of Educational Psychology, 91*(2), 358–368.

Pasaréti, O., Hajdin, H., Matusaka, T., Jambori, A., Molnar, I., Tucsányi-Szabó, M. (2011). Augmented Reality in education. *INFODIDACT 2011 Informatika Szakmódszertani Konferencia*.

Qiao, X., Ren, P., Dustdar, S., Liu, L., Ma, H., Chen, J. (2019). Web AR: A promising future for mobile augmented reality – State of the art, challenges, and insights. *Proceedings of the IEEE, 107*(4), 651–666.

Rudolph, M. (2017). Cognitive theory of multimedia learning. *Journal of Online Higher Education, 1*(2), 1–10.

Töröková, M., Török, J., Kočiško, M., Kaščak, J. (2020). Augmented reality as a support tool in machining process. *Tem Journal, 9*(1), 407–411.

Wu, H.K., Lee, S.W.Y., Chang, H.Y., Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & education*, *62*, 41–49.

Zlatanova, S. (2002). *Augmented reality technology*. GISt Report No. 17, Delft.