Design and implementation of accessible open-source augmented reality learning authoring tool

Deogratias Shidende[a,b]

[a] University of Hohenheim, Schloss Hohenheim 1, 70599 Stuttgart, Germany
[b] Duale Hochschule Baden-Württemberg (DHBW) Heidenheim, Marienstraße 20, 89518 Heidenheim, Germany

Abstract

The emerging learning technologies have brought new dimensions to the learning process. Particularly in this era, where due to health reasons, online learning is preferred, augmenting reality with digital information is paramount. Unfortunately, most of the existing augmented reality learning applications were not designed for different abilities, apart from having substantial annual licenses. Further, they require advanced digital competence such as programming, which many non-technical educational practitioners lack. This research attempts to fill this gap by designing and implementing an accessible open-source augmented reality learning authoring tool that will empower non-technical educational practitioners of different abilities to develop and use augmented reality applications for teaching and learning purposes.

Keywords [1]

Learning Technologies, Augmented Reality, Augmented Reality Learning, Accessibility, Open-source

1. Introduction

Augmented Reality (AR) is a technology that superimposes real-world objects with virtual generated information in the same space, thus providing a more useful composite view. While AR is widely used with the sense of sight, it also applies to smell, touch, and hearing senses [1].

Since its inception, AR has been used in a wide range of applications, including entertainment, mapping, transportation, health, and education sectors. At first, AR was introduced as a training tool for airline and Air Force pilots during the 1960s [2]. Due to the advancement in information technology, AR is currently implemented in computer and mobile devices without requiring expensive technology such as head-mounted displays [3]. For learning purposes, AR creates immersive hybrid learning environments that facilitate critical thinking, problem-solving, and communicating through interdependent collaborative exercises [4–6]. Other studies by Akçayır *et al.* [7] and Mylonas *et al.* [8] revealed that AR improves university students' laboratory skills and helps them build positive attitudes. A variety of research projects examined the initial suitability of AR for different learning scenarios, e.g. flipped learning or experiential learning, and in various disciplines [9–12] as well as its integration in teaching and learning processes [13].

However, studies show that most AR applications have been developed using proprietary Software Development Kit (SDK) such as Vuforia, Kudan AR, Adobe Aero, and Wikitude [5]. These are potent tools for handling all three AR system stages, namely recognition, tracking, and mixing, allowing ease of development for the developers [14], [15]. However, these AR tools are not open-source, and they carry heavy, substantial annual license fees. This represents an obstacle for

Proceedings of the Doctoral Consortium of Sixteenth European Conference on Technology Enhanced Learning, September 20–21, 2021, Bolzano, Italy (online).
EMAIL: deogratias.shidende@dhbw-heidenheim.de (Deogratias Shidende)
ORCID: 0000-0002-2181-958X (Deogratias Shidende)

many small to mid-sized companies as well as institutions of higher education alike.

In fact, open-source software does not only refer to the availability of source code. Moreover, it designates a broader sense of values that embraces and celebrates open exchange principles, collaborative participation, rapid prototyping, transparency, meritocracy, and community-oriented development [16, 17]. By developing an open-source tool, programmers and software users benefit from the control over the tool, training from the communities behind it, security, and stability. Thus, an open-source AR tool will benefit from using existing parts of an open-source learning tool and enhance it for AR authoring. Therefore, it provides an authoring tool available with an open-source license for use and opens for further future development by business partners and other stakeholders.

Research further reveals that few AR applications have been developed by using an open-source library such as ARToolkit, AR.js and DroidAR. With these libraries, programmers are using traditional languages such as c#, c/c++, python, Java and JavaScript to develop AR applications [5, 14]. This means, developing AR applications requires technical knowledge in these programming languages or hiring computer programmers. Unfortunately, many non-technical instructors lack this digital competence [18–20]. Also, it is costly to hire a programmer for mid-sized companies and educational institutions [21]. Furthermore, most of these applications are challenged with usability problems, inadequate technology experience, interface design errors, and technical difficulties [3, 22–24].

World Health Organisation estimates about 15% of the world's population have at least one particular form of disability. This number increases due to increased chronic diseases, ageing, and technology discovery to identify various disabilities [25]. The various forms of disabilities include auditory, cognitive, learning and neurological, physical, speech and visual disabilities. These forms require different approaches and strategies to reduce the obstacles in accessing the AR applications [26]. Most existing AR Learning applications, however, target one form of disability. For example, a multi-sensory AR map targets blind and low vision students [27], whereas MoviLetrando targets Autism Spectrum Disorder students [28]. Other authors dealt with the auditory ability [29], low vision [30] and cognitive support [31]. Unfortunately, research shows that many proprietary and open-source AR applications are not designed for users with different abilities [32–34] and exclude many people who would benefit from these applications.

This research, therefore, aims to use existing open-source libraries and approaches to design and implement an inclusive and accessible AR tool based on an open-source learning environment, such as Moodle. It can be used to author AR learning in different disciplines by users with varying levels of accessibility and in different learning settings, from university classrooms and for on-the-job training.

2. Research objectives and questions

The main objective is to develop an accessible augmented reality learning authoring tool. Specifically, the research aims the following

1. To identify the requirements for developing an open-source AR learning authoring tool
2. To develop an open-source tool for authoring AR learning, building on an existing OS learning platform.
3. To validate the AR authoring tool through authoring a pilot AR learning application

This thesis intends to answer the following main question: How can you design and implement an augmented reality learning authoring tool for a broad audience? The secondary research questions are as follows: -

1. What are the requirements for developing an accessible open-source AR learning authoring tool?
2. How can we develop an accessible open-source augmented reality learning authoring tool?
3. What kind of AR learning applications can be authored with the tool?

3. Theoretical framework

The combination of real-world with multimedia elements is one of the promising technologies in the field of education. This follows from the cognitive theory of multimedia learning, which states that people learn better when the instruction is given using both words and pictures than words alone [35]. Further, Buchem et al. [36] argue that AR is characterised by various affordances such as embodied, collaborative, and augmentative affordances. These affordances make AR indispensable in a learning environment as it forages helpful information for learners and constructs more profound knowledge.

Though Garzón noted that the effectiveness of AR in learning is medium [33], numerous studies have reported the interaction between learner and AR artefacts is potent in learning. For instance, AR learning has resulted in learning gain and motivation [3, 32, 37, 38], content understanding and retention [32, 39–41], increased interaction and attention [42, 43], learning efficiency and performance [44, 45] and enhances problem-solving abilities and influence decision making [3, 5].

Various other examples have proved that AR is beneficial in teaching and learning. For instance, Mylonas et al. [8] used AR as a visual aid to teach students how electrical devices consume energy. Fidan and Tuncel [46] integrated AR application with problem-based learning activities to help students understood physics concepts and improve their attitudes towards physics.

Like any other technology, AR is not without challenges and limitations. Alalwan et al. [47] conducted a semi-structured interview with 29 science teachers in a developing country. They found that teachers' competency, proper instructional design and resources were common limitations in AR utilisation. Also, Pellas *et al*. [48] pointed out that teachers could not modify or add content to AR applications. These teachers' incapability might be because most non-technical teachers are at the basic-level of digital competence [49, 50]. Dirin & Laine [51] found usability problems, when evaluated two mobile AR applications. The usability problems in AR are also reported by other researchers [3, 23, 24]. While the usability problems can be solved through following good design principles, Buchem et al [36] proposes interdisciplinary training to alleviate digital illiteracy among educational practioners.

Accessibility is a concept that ensures a product or service is usable by people with different abilities. Designing for accessibility widens a pool of users, opens equal opportunity for various user types and increases the compatibilities with other devices [52, 53]. Accessibility is more than technical standards, it is also a moral obligation and legal requirement. For instance, European Union directives 2016/2102 directs websites and mobile applications of the public sector to be accessible [54].

Despite its significance, many AR applications do not consider accessibility in the early design stage, or they are dealing with one form of ability. Examples of AR studies with a particular ability are numerous. Mentioning a few are Albouys-Perrois *et al*. [27] implemented a Multi-sensory AR map for blind and low vision students by using text-to-speech, tactile tools, and visual calibrated projector. Antão et al [28] improved the performance and reaction time skills of Autism Spectrum Disorder students using the AR computer game MoviLetrando. In auditory ability, Al-Megren & Almutairi [55] developed a mobile application that uses AR to support literacy among hard of hearing children. Another study employed AR to give cognitive support during assembly tasks [31]. Further, a systematic review by Garzón [33] of 61 selected AR in education settings articles from 2012-2018 revealed that only one paper dealt with the accessibility of AR learning. This finding agreed with previous studies by [32] and [34], whose results showed very few systems designed for users with diverse needs.

However, designing for accessibility is more than considering a particular form of disability; it is adhering to accessibility guidelines and standards such as Web Content Accessibility Guidelines (WCAG 2.1) [56] and IEEE Standard for Augmented Reality Learning Experience Model [57]. In addition, consider XR Accessibility User Requirements [58] and follow developers' guidelines such as the XR Association Developer guide [59], helpful in making an XR application accessible. Thus, the development of an accessible AR authoring tool intends to comply with the mentioned standards, guidelines, and use cases, particularly level AA of WCAG 2.1.

Open-source is both a legal term and a development model [60]. Legally, it is governed by an open-source license, a license that is approved by Open Source Initiative (OSI). This license gives the software users the legal power of using, inspecting, modifying and distributing the software source code. These rights are outlined in the ten characteristics of the Open-Source Definition (OSD) [60, 61].

Whether the open-source software will be free of charge or not will depend on the adopted business model and the open-source license used [62].

As a development model, Open-source can be developed in a distributed manner with developers scattered geographically and organisationally [63]. This peer-reviewed manner of development can foster different organisations, such as Universities and companies, to cooperate in producing reliable, cheaper, and faster-delivery software [64]. AlMarzouq et al. [60] argued that the quality of open-source software depends on license, community, and development process. The license, for instance, decides which components to use and encourages or discourages community participation. While the motivated community is essential, the development process determines feedback speed and the review process. Thus, this study intends to adopt an Open-Source license that will enable partner universities and companies to participate in the development of accessible AR learning tool.

4. Research methods

This research aims to design and implement an accessible open-source augmented reality learning authoring tool for non-technical instructors with different levels of abilities. The guiding research methods will be Design-based Research (DBR) blended with Agile Methodology in Scrumban (AMS). While various researchers have successfully used DBR to develop learning interventions [65–67], AMS is an effective project management methodology in information systems development [65]. Both DBR and AMS are iterative and involve practitioners from the early stages of problem analysis to product acceptance. Despite its success, some studies have reported the challenges of DBR. These include researchers' biases [66, 67], the possibility of iterations to exceed available resources [66], and the inapplicability of interventions in different settings [68]. AMS, on another side, has been reported to have a positive influence in both project management knowledge areas and project management triple constraints, i.e. scope, cost and time [69]. Unfortunately, applying AMS to create an intervention without creating knowledge is not research [70, 71]. Thus, we anticipate that AMS and designed research to develop an intervention can complement each other. Some studies that have hybridised the DBR with agility include Cochrane [72], Cooney [73] and Dass [74].

The research will be carried out in higher learning institutions and partner companies located in Germany and Tanzania. The partner universities and companies will provide both educational practitioners and customers. Like other DBR approaches, we will follow a pragmatic paradigm by using appropriate qualitative and quantitative methods [67, 75] such as surveys, interviews, focus groups, and document reviews.

Further, we will follow the DBR processes as outlined by Plomp [70]. Plomp examined various researches conducted by using DBR and concluded the following three phases. The first phase is preliminary research comprising practical problem analysis, literature review and conceptual or theoretical framework development. The second is the development phase, in which the prototype is iteratively developed as a micro-cycle of the research with formative evaluations. And the last is the assessment phase consisting of summative evaluation to check if the intervention meets the agreed specifications [70, 76]. These three phases are conducted iteratively [71, 77].

The AMS consists of roles, processes and artefacts. The roles are scrum master and scrum team. The activities in the process include kickoff, the meeting to plan the sprint, sprint execution, the daily Scrum and the sprint review meeting. The iteration, also known as a sprint, should be planned such that it is completed in a short time. The last component of AMS is scrum artefacts: these are product backlog, sprint backlog, and burnout charts [65]. Thus, since AMS focus on sprints with small deliverables and direct communication among the partners, it can help adapt quickly to the project unpredictability and become helpful to DBR, as shown by Kastl and Romeike [78] and Confrey [79]. They applied the agile methodology to improve intra-communication, team member cooperation and active participation in the DBR design activities.

5. Current status and future work

This work started in January 2021, and it is currently in the completion of the first phase of DBR, specifically, literature review and framework development.

The next steps to accomplish this work are as follows: - To start the data collection and prototype development, employing AMS in prototype development and conducting the summative evaluation. This will be followed by phase three, which is a summative evaluation of the work. We expect to do two to three iterations of this phase model in the next twelve months.

6. Expected contributions

This research will contribute to the empirical knowledge concerning accessible open-source AR learning. Primarily, it will add knowledge on the usage of open-source libraries and approaches in developing an authoring tool for an AR learning tool. The knowledge will be helpful to researchers, academicians, and other enthusiasts to expand the research and extend the work for different educational and societal needs.

It will provide source code for the accessible environment to create AR resources and thus, contribute an interface for non-technical authors to develop AR learning applications suitable for teaching at universities and on-the-job training. We believe students and teachers will achieve their curricula demands through these AR Learning applications.

7. Acknowledgements

This research work is funded by Baden-Württemberg Cooperative State University (DHBW) through the Innovationsprogramm Forschung (IPF). Specifically, the special thanks go to DHBW Heidenheim, which are hosting the AuReLiA - Augmented Reality Learning and Accessibility research laboratory, the partner company Graustich and the partner university Nelson Mandela African Institution of Science and Technology (NM-AIST) Arusha. The views expressed in this document are authors'; hence the DHBW, NM-AIST and Graustich are not responsible for any information it may contain.

8. References

[1] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, ‘Recent advances in augmented reality’, IEEE Comput. Graph. Appl., vol. 21, no. 6, pp. 34–47, 2001.

[2] T. Furness, ‘Helmet-mounted displays and their aerospace applications’, in National Aerospace Electronics Conference, 1969, vol. 1.

[3] M. Akçayır and G. Akçayır, ‘Advantages and challenges associated with augmented reality for education: A systematic review of the literature’, Educ. Res. Rev., vol. 20, pp. 1–11, 2017.

[4] M. Dunleavy, C. Dede, and R. Mitchell, ‘Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning’, J. Sci. Educ. Technol., vol. 18, no. 1, pp. 7–22, 2009.

[5] M.-B. Ibáñez and C. Delgado-Kloos, ‘Augmented reality for STEM learning: A systematic review’, Comput. Educ., vol. 123, pp. 109–123, 2018.

[6] L. López-Faican and J. Jaen, ‘EmoFindAR: Evaluation of a mobile multiplayer augmented reality game for primary school children’, Comput. Educ., vol. 149, p. 103814, 2020, doi: 10.1016/j.compedu.2020.103814.

[7] M. Akçayır, G. Akçayır, H. M. Pektaş, and M. A. Ocak, ‘Augmented reality in science laboratories: The effects of augmented reality on university students’ laboratory skills and attitudes toward science laboratories’, Comput. Hum. Behav., vol. 57, pp. 334–342, 2016.

[8] G. Mylonas, C. Triantafyllis, and D. Amaxilatis, ‘An Augmented Reality Prototype for supporting IoT-based Educational Activities for Energy-efficient School Buildings’, Electron. Notes Theor. Comput. Sci., vol. 343, pp. 89–101, 2019, doi: 10.1016/j.entcs.2019.04.012.

[9] S.-C. Chang and G.-J. Hwang, ‘Impacts of an augmented reality-based flipped learning guiding approach on students’ scientific project performance and perceptions’, Comput. Educ., vol. 125, pp. 226–239, 2018.

[10] J. A. Frank and V. Kapila, ‘Mixed-reality learning environments: Integrating mobile interfaces with laboratory test-beds’, Comput. Educ., vol. 110, pp. 88–104, 2017.

[11] T.-C. Huang, C.-C. Chen, and Y.-W. Chou, ‘Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment’, Comput. Educ., vol. 96, pp. 72–82, 2016.

[12] R. Layona, B. Yulianto, and Y. Tunardi, ‘Web based augmented reality for human body anatomy learning’, Procedia Comput. Sci., vol. 135, pp. 457–464, 2018.

[13] D. Sampaio and P. Almeida, ‘Pedagogical strategies for the integration of Augmented Reality in ICT teaching and learning processes’, Procedia Comput. Sci., vol. 100, pp. 894–899, 2016.

[14] D. Amin and S. Govilkar, ‘Comparative study of augmented reality SDKs’, Int. J. Comput. Sci. Appl., vol. 5, no. 1, pp. 11–26, 2015.

[15] A. Hanafi, L. Elaachak, and M. Bouhorma, ‘A comparative Study of Augmented Reality SDKs to Develop an Educational Application in Chemical Field’, in Proceedings of the 2nd International Conference on Networking, Information Systems & Security, New York, NY, USA, 2019, pp. 1–8. doi: 10.1145/3320326.3320386.

[16] F. Joseph, F. Brian, and S. Raymond Eric, ‘Understanding open source software development’. Addison Wesley, Pearson Education Book, 2001.

[17] opensource.com, ‘What is open source?’ https://opensource.com/resources/what-open-source.

[18] R. Colpani and M. R. P. Homem, ‘An innovative augmented reality educational framework with gamification to assist the learning process of children with intellectual disabilities’, in 2015 6th International Conference on Information, Intelligence, Systems and Applications (IISA), 2015, pp. 1–6. doi: 10.1109/IISA.2015.7387964.

[19] J. B. Osuna, J. Gutiérrez-Castillo, M. Llorente-Cejudo, and R. V. Ortiz, ‘Difficulties in the incorporation of augmented reality in university education: Visions from the experts’, J. New Approaches Educ. Res. NAER J., vol. 8, no. 2, pp. 126–141, 2019.

[20] S. Tzima, G. Styliaras, and A. Bassounas, ‘Augmented Reality Applications in Education: Teachers Point of View’, Educ. Sci., vol. 9, no. 2, Art. no. 2, 2019, doi: 10.3390/educsci9020099.

[21] C. Lytridis and A. Tsinakos, ‘Evaluation of the ARTutor augmented reality educational platform in tertiary education’, Smart Learn. Environ., vol. 5, no. 1, pp. 1–15, 2018.

[22] K.-E. Chang, C.-T. Chang, H.-T. Hou, Y.-T. Sung, H.-L. Chao, and C.-M. Lee, ‘Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum’, Comput. Educ., vol. 71, pp. 185–197, 2014.

[23] N. Gavish et al., ‘Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks’, Interact. Learn. Environ., vol. 23, no. 6, pp. 778–798, 2015.

[24] B. S. Hantono, L. E. Nugroho, and P. I. Santosa, ‘Meta-Review of Augmented Reality in Education’, in 2018 10th International Conference on Information Technology and Electrical Engineering (ICITEE), 2018, pp. 312–315. doi: 10.1109/ICITEED.2018.8534888.

[25] World Health Organisation, ‘World Report on Disability’, World Health Organisation, Malta, 2011. [Online]. URL: https://www.who.int/disabilities/world_report/2011/report.pdf

[26] A. Tesolin and A. Tsinakos, ‘Opening Real Doors: Strategies for Using Mobile Augmented Reality to Create Inclusive Distance Education for Learners with Different-Abilities’, in Mobile and Ubiquitous Learning: An International Handbook, S. Yu, M. Ally, and A. Tsinakos, Eds. Singapore: Springer, 2018, pp. 59–80. doi: 10.1007/978-981-10-6144-8_4.

[27] J. Albouys-Perrois, J. Laviole, C. Briant, and A. M. Brock, ‘Towards a Multisensory Augmented Reality Map for Blind and Low Vision People: a Participatory Design Approach’, in Proceedings of the 2018 CHI Conference on Human Factors in Computing

Systems, New York, NY, USA, 2018, pp. 1–14. doi: 10.1145/3173574.3174203.

[28] J. Y. F. de L. Antão et al., 'Use of Augmented Reality with a Motion-Controlled Game Utilizing Alphabet Letters and Numbers to Improve Performance and Reaction Time Skills for People with Autism Spectrum Disorder', Cyberpsychology Behav. Soc. Netw., vol. 23, no. 1, pp. 16–22, 2020, doi: 10.1089/cyber.2019.0103.

[29] A. Almutairi and S. Al-Megren, 'Preliminary investigations on augmented reality for the literacy development of deaf children', in International Visual Informatics Conference, 2017, pp. 412–422.

[30] J. Herskovitz et al., 'Making Mobile Augmented Reality Applications Accessible', 22nd Int. ACM SIGACCESS Conf. Comput. Access., pp. 1–14, 2020, doi: 10.1145/3373625.3417006.

[31] P. Vanneste, Y. Huang, J. Y. Park, F. Cornillie, B. Decloedt, and W. Van den Noortgate, 'Cognitive support for assembly operations by means of augmented reality: an exploratory study', Int. J. Hum.-Comput. Stud., vol. 143, p. 102480, 2020, doi: 10.1016/j.ijhcs.2020.102480.

[32] J. L. Bacca Acosta, S. M. Baldiris Navarro, R. Fabregat Gesa, and S. Graf, 'Augmented reality trends in education: a systematic review of research and applications', J. Educ. Technol. Soc. 2014 Vol 17 Núm 4 P 133-149, 2014.

[33] J. Garzón, J. Pavón, and S. Baldiris, 'Systematic review and meta-analysis of augmented reality in educational settings', Virtual Real., vol. 23, no. 4, pp. 447–459, 2019, doi: 10.1007/s10055-019-00379-9.

[34] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang, 'Current status, opportunities and challenges of augmented reality in education', Comput. Educ., vol. 62, pp. 41–49, 2013.

[35] R. E. Mayer, The Cambridge handbook of multimedia learning. Cambridge university press, 2005.

[36] I. Buchem, R. Klamma, and F. Wild, 'Introduction to Wearable Enhanced Learning (WELL): Trends, Opportunities, and Challenges', in Perspectives on Wearable Enhanced Learning (WELL): Current Trends, Research, and Practice, I. Buchem, R. Klamma, and F. Wild, Eds. Cham: Springer International Publishing, 2019, pp. 3–32. doi: 10.1007/978-3-319-64301-4_1.

[37] I. Radu, 'Why should my students use AR? A comparative review of the educational impacts of augmented-reality', in 2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2012, pp. 313–314.

[38] J. Buchner and J. Zumbach, 'Promoting Intrinsic Motivation with a Mobile Augmented Reality Learning Environment.', Int. Assoc. Dev. Inf. Soc., 2018.

[39] A. M. Kamarainen et al., 'EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips', Comput. Educ., vol. 68, pp. 545–556, 2013.

[40] I. Radu, 'Augmented reality in education: a meta-review and cross-media analysis', Pers. Ubiquitous Comput., vol. 18, no. 6, pp. 1533–1543, 2014.

[41] M. H. Kurniawan and G. Witjaksono, 'Human anatomy learning systems using augmented reality on mobile application', Procedia Comput. Sci., vol. 135, pp. 80–88, 2018.

[42] T. H. Chiang, S. J. Yang, and G.-J. Hwang, 'Students' online interactive patterns in augmented reality-based inquiry activities', Comput. Educ., vol. 78, pp. 97–108, 2014.

[43] M. C. Costa, J. M. Patricio, J. A. Carrança, and B. Farropo, 'Augmented reality technologies to promote STEM learning', in 2018 13th Iberian Conference on Information Systems and Technologies (CISTI), 2018, pp. 1–4.

[44] E. Liu, Y. Li, S. Cai, and X. Li, 'The effect of augmented reality in solid geometry class on students' learning performance and attitudes', in International Conference on Remote Engineering and Virtual Instrumentation, 2018, pp. 549–558.

[45] S. Radosavljevic, V. Radosavljevic, and B. Grgurovic, 'The potential of implementing augmented reality into vocational higher education through mobile learning', Interact. Learn.

Environ., vol. 28, no. 4, pp. 404–418, 2020.

[46] M. Fidan and M. Tuncel, ‘Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education’, Comput. Educ., vol. 142, p. 103635, 2019.

[47] N. Alalwan, L. Cheng, H. Al-Samarraie, R. Yousef, A. Ibrahim Alzahrani, and S. M. Sarsam, ‘Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective’, Stud. Educ. Eval., vol. 66, p. 100876, 2020, doi: 10.1016/j.stueduc.2020.100876.

[48] N. Pellas, P. Fotaris, I. Kazanidis, and D. Wells, ‘Augmenting the learning experience in primary and secondary school education: a systematic review of recent trends in augmented reality game-based learning’, Virtual Real., vol. 23, no. 4, pp. 329–346, 2019, doi: 10.1007/s10055-018-0347-2.

[49] OECD, ‘TALIS 2018 Results (Volume I): Teachers and School Leaders as Lifelong Learners’. OECD Publishing, Paris, 2019. [Online]. URL: https://www.oecd-ilibrary.org/content/publication/1d0bc92a-en

[50] F. Caena and C. Redecker, ‘Aligning teacher competence frameworks to 21st century challenges: The case for the European Digital Competence Framework for Educators (Digcompedu)’, Eur. J. Educ., vol. 54, no. 3, pp. 356–369, 2019.

[51] A. Dirin and T. H. Laine, ‘User Experience in Mobile Augmented Reality: Emotions, Challenges, Opportunities and Best Practices’, Computers, vol. 7, no. 2, Art. no. 2, Jun. 2018, doi: 10.3390/computers7020033.

[52] P. Acosta-Vargas, L. Antonio Salvador-Ullauri, and S. Luján-Mora, ‘A Heuristic Method to Evaluate Web Accessibility for Users With Low Vision’, IEEE Access, vol. 7, pp. 125634–125648, 2019, doi: 10.1109/ACCESS.2019.2939068.

[53] S. Kurt, ‘Moving toward a universally accessible web: Web accessibility and education’, Assist. Technol., vol. 31, no. 4, pp. 199–208, 2019, doi: 10.1080/10400435.2017.1414086.

[54] E. Lex, ‘Directive (EU) 2016/2102 of the European Parliament and of the Council of 26 October 2016 on the accessibility of the websites and mobile applications of public sector bodies’, Off. J., pp. 1–15, 2016.

[55] S. Al-Megren and A. Almutairi, ‘User requirement analysis of a mobile augmented reality application to support literacy development amongst children with hearing impairments’, J. Inf. Commun. Technol., vol. 18, no. 2, pp. 207–231, 2019.

[56] W3C Web Accessibility Initiative (WAI), ‘Web Content Accessibility Guidelines (WCAG) Overview’, Web Accessibility Initiative (WAI), 2018. https://www.w3.org/WAI/standards-guidelines/wcag/.

[57] F. Wild, C. Perey, B. Hensen, and R. Klamma, ‘IEEE Standard for Augmented Reality Learning Experience Models’, in 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), 2020, pp. 1–3.

[58] W3C Web Accessibility Initiative (WAI), ‘XR Accessibility User Requirements’, 2021. https://www.w3.org/TR/xaur/.

[59] XR Association, ‘XR ASSOCIATION DEVELOPERS GUIDE’, XR Association, 2020.

[60] M. AlMarzouq, L. Zheng, G. Rong, and V. Grover, ‘Open source: Concepts, benefits, and challenges’, Commun. Assoc. Inf. Syst., vol. 16, no. 1, p. 37, 2005.

[61] Open Source Initiative, ‘The Open Source Definition | Open Source Initiative’, 2007. https://opensource.org/docs/definition.html.

[62] M. Heron, V. L. Hanson, and I. Ricketts, ‘Open source and accessibility: advantages and limitations’, J. Interact. Sci., vol. 1, no. 1, pp. 1–10, 2013.

[63] K. Crowston, K. Wei, J. Howison, and A. Wiggins, ‘Free/Libre open-source software development: What we know and what we do not know’, ACM Comput. Surv. CSUR, vol. 44, no. 2, pp. 1–35, 2008.

[64] J. DJurković, V. Vuković, and L. Raković, ‘Open Source Approach in Software Development—Advantages and

Disadvantages', Manag Inforation Syst, vol. 3, pp. 029–033, 2008.
[65] H. F. Cervone, 'Understanding agile project management methods using Scrum', OCLC Syst. Serv. Int. Digit. Libr. Perspect., vol. 27, no. 1, pp. 18–22, 2011, doi: 10.1108/10650751111106528.
[66] T. Anderson and J. Shattuck, 'Design-Based Research: A Decade of Progress in Education Research?', Educ. Res., vol. 41, no. 1, pp. 16–25, 2012, doi: 10.3102/0013189X11428813.
[67] S. Barab and K. Squire, 'Design-Based Research: Putting a Stake in the Ground', J. Learn. Sci., vol. 13, no. 1, pp. 1–14, Jan. 2004, doi: 10.1207/s15327809jls1301_1.
[68] Design-Based Research Collective, 'Design-based research: An emerging paradigm for educational inquiry', Educ. Res., vol. 32, no. 1, pp. 5–8, 2003.
[69] F. Hayat, A. U. Rehman, K. S. Arif, K. Wahab, and M. Abbas, 'The Influence of Agile Methodology (Scrum) on Software Project Management', in 2019 20th IEEE/ACIS International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD), Jul. 2019, pp. 145–149. doi: 10.1109/SNPD.2019.8935813.
[70] T. Plomp, 'Educational design research: An introduction', Educ. Des. Res., pp. 11–50, 2013.
[71] T. REEVES, 'Design research from a technology perspective', in Educational Design Research, Routledge, 2006.
[72] T. Cochrane, 'hybrid Design based research for Agile Software development (hDAS) in ISD contexts: a discovery from studying how to design MUVEs for VET', in 6th International Conference on Higher Education Advances (HEAd'20), 2020, no. 30-05–2020, pp. 875–882.
[73] L. Cooney and A. Little, 'Implementation of Agile Methods within Instructional Systems Design: A Case Study, 12', 2015.
[74] D. S. Dass and V. Cid, 'An Agile ISD Process to Develop a Medical Simulation, 10', 2018.
[75] F. Wang and M. J. Hannafin, 'Design-based research and technology-enhanced learning environments', Educ. Technol. Res. Dev., vol. 53, no. 4, pp. 5–23, 2005, doi: 10.1007/BF02504682.
[76] A. H. Alghamdi and L. Li, 'Adapting design-based research as a research methodology in educational settings', Int. J. Educ. Res., vol. 1, no. 10, pp. 1–12, 2013.
[77] Y. Ma and S. W. Harmon, 'A Case Study of Design-Based Research for Creating a Vision Prototype of a Technology-Based Innovative Learning Environment', J. Interact. Learn. Res., vol. 20, no. 1, pp. 75–93, 2009.
[78] P. Kastl and R. Romeike, 'Towards agile practices in CS secondary education with a design based research approach', in Proceedings of the 9th Workshop in Primary and Secondary Computing Education, New York, NY, USA, 2014, pp. 130–131. doi: 10.1145/2670757.2670776.
[79] J. Confrey, 'Leading a Design-Based Research Team Using Agile Methodologies to Build Learner-Centered Software', in Designing, Conducting, and Publishing Quality Research in Mathematics Education, K. R. Leatham, Ed. Cham: Springer International Publishing, 2019, pp. 123–142. doi: 10.1007/978-3-030-23505-5_9.