A Mixed-Reality Environment for Personalised and Collaborative Learning in Science and Engineering

Clement Onime[1,3](✉), James Uhomoibhi[2], and Hui Wang[2]

[1] International Centre for Theoretical Physics, Trieste, Italy
onime@ictp.it
[2] Ulster University, Belfast, Northern Ireland
{j.uhomoibhi,h.wang}@ulster.ac.uk
[3] African University of Science and Technology, Abuja, Nigeria

Abstract. Mixed reality environments as in-betweens of real-world and virtual-reality (VR) environments are created by combining real world objects with computer generated ones. In general, mixed-reality along with VR technology provides innovative ways of showing relationships and connections in the real world, mainly by complimenting real objects with additional information (text, audio and video overlays). In Science Technology and Engineering (STE) disciplines, collaborative learning is about learners working together in teams or groups on structured learning tasks, that typically have a clearly defined goal and are arranged in such a manner that all members of the team are involved. A collaborative approach builds individual and group accountability in each learner as well as one or more soft skills such as communicating with peers, managing resources and the ability to make decisions. This paper presents the use of mixed-reality environments for personalised learning along with two approaches based on message passing paradigms for implementing collaborative learning in mixed-reality environments. The first approach shows the use of a pair of geographically distant mixed-reality environments for remote collaborative learning, while the second approach show multiple (independent) mixed-reality tools synchronised for co-located group work/learning. The statistical analysis of a research study with over 70 respondents from STE disciplines who were exposed to mixed-reality tools developed using mobile technology is also presented and discussed in the context of collaborative work within mixed-reality environments. The contributions includes unique implementations of mixed-reality based collaborative learning environments capable of providing similar experience to that obtained from traditional real-world environments.

Keywords: Mixed-reality · Collaborative-learning

M. E. Auer et al. (eds.), *Teaching and Learning in a Digital World*,
Advances in Intelligent Systems and Computing 716,
https://doi.org/10.1007/978-3-319-73204-6_62

1 Introduction

In collaborative learning learners cooperatively work together in teams or groups on structured learning tasks that typically have a clearly defined goal and are arranged in such a manner that all members of a team or a group are involved. Generally, participation in these task requires both individual and group accountability from each team-member for the development of one or more soft skills such as communicating with peers, managing resources (time) and the ability to make or modify decisions based on contributions of others. In collaborative learning, it is important for the team members to meet periodically to promote individual and collective development/improvements. Some examples of structured learning tasks in Science and Engineering includes teams/groups for completing assignments, report writing, just studying for an examination or test [12] and joint research-work towards subject based projects and problems. Instructors (teachers) as educators play a less central role in collaborative learning because learners take more responsibility for their own learning [24]. The knowledge acquired by each learner is uniquely constructed from individual prior experiences, interactions with other learners and their collective experiences. This implies that the knowledge acquired by a learner is growing over time and is also individually personalized to the particular group of collaborating learners.

Mixed reality environments as in-betweens of real-world and virtual-reality (VR) environments are created by combining real world objects with computer generated ones. The Augmented Reality (AR) form of mixed-reality is already present in many every-day applications, such as live-television broadcast of sports events [3]. In general mixed-reality along with VR technology provides innovative ways of showing relationships and connections in the real world. Many educational applications of mixed-reality environments including [28,29] work by complimenting real objects with additional (passive) information (text, audio and video overlays). While, computers and other ICT tools are regularly used in learning and research, sometimes for processing, transformations or presentations [7]; mixed-reality environments are better suited for integrating research data/outputs across a variety of media formats for enhanced presentation of real-world objects during the learning process [9]. Most examples of mixed-reality environments show good support for personalised learning where collaboration is typically limited to the shared use of a single (common) mixed-reality tool for visualisation and learning by all learners co-located in the same room/environment.

This paper examines the use of mixed-reality environments for collaborative and personalised learning and is structured as follows: Sect. 2 reviews relevant concepts, standards and goals of collaborative and personalised learning applicable to mixed-reality environments. While, Sect. 3 presents two approaches based on message passing paradigms for implementing collaborative learning in mixed-reality environments. Section 4 discusses the findings and statistical analysis of results from a questionnaire based study of mixed-reality environments in Science and Technology before concluding in Sect. 5.

2 Background

In most Science and Engineering programmes, teaching (lecturing and possibly with additional tutoring) would be carried out before the learners are exposed to collaborative learning tasks designed to illustrate or illuminate the prior taught (or learnt) theories and concepts. For example, in capstone projects, learners are grouped in small teams of up to eight individuals to undertake a given project and informally exchange and share information amongst themselves. Here, learners may also acquire additional soft skills in the area of collaborative engineering design [24]. These structured learning tasks may also require learners individually plan and implement some aspects practically and/or subsequently produce an individual final written report as a terminal part of the training.

An alternative to capstone projects involves the introduction of problems before the classes (lectures and tutorials) on relevant topics are held. The expectation is that the learners having an immediate objective or purpose would then study/investigate topics deeper seeking to discover answers to the problems as part of the learning process that would occur during subsequent lectures and tutorials [16]. Sometimes, the teacher or instructor also intertwines the problem or project into the normal class (or alongside the normal class) lessons on the theory, as this encourages learners to readily connect and associate the (highlighted by instructor or teacher) facts and other theoretical concepts to potential or actual solutions to the problem as soon as they learn them.

Capstone projects in collaborative learning may provide a rather limited perspective of the real-world, that does not reflect the actual situations occurring in a real industry environment, even when the projects (or challenges) are provided directly or in-directly by a relevant industry partner. Another approach to collaborative learning involves the learners also participating in the running of a simulated company or industry specially set-up around the project. The learners are fully involved in all aspects of the simulated company including the determination of the various positions available and other aspects of the company structure. The learners would prepare their own curriculum vitae and apply for the various positions in the simulated company. Subsequently, they also participate in the evaluation and selection process for filling the various positions. The chief executive officer in the simulated company is played by an instructor or tutor acting only as a passive advisor providing limited guidance to the learners. The simulated company usually has about thirty staff (learners) who would form several operational teams required to complete the project work [6].

Another example of collaborative learning, involves communication and exchange of ideas across different generations of scientists and engineers. As [27] pointed out, the problems and challenges faced in industry as well as the associated solutions are hardly static and the use of mentors across generation would ensure the growth and exchange of know-how between industry (older engineers as mentors) and young/upcoming engineers. A commonly used technique is for individual learners to spend a period (up-to 6 months) of training (attachment) with some industry partner acquiring working (practical) knowledge from the older scientists or engineer [34]. Learners would then subsequently or periodically meet in organised research seminars/forums to collectively present, share and exchange highlights from their individual experiences as well as collectively brainstorm to address identified challenges, possibly in the presence of older scientists and engineers.

2.1 Mobile Mixed Reality

Mixed-reality system combine real world objects with computer generated ones within an apparently seamless viewing space while allowing some user interactions with one or more computer generated objects in real-time. Mixed reality technology is potentially limitless in its ability to provide an enhanced view of the world or environment around a user and by extension its ability to enhance derivable learning from surrounding environment. Technologically, mixed reality systems usually require a hardware capture device such as a camera, combined with a processing element running a suitable mixed reality software application that performs the required transformations in real-time before display on a hardware output device such as a display-screen.

According to [25], the two main types of mixed reality are Augmented Reality (AR) and Augmented Virtuality (AV) [30]. In AR, the resulting view is predominantly made of real objects while in AV, the resulting view is predominantly made up of computer generated (virtual) objects. Most works and examples of mixed reality systems tend to focus heavily on the visual domain, at the expense of other forms of such as auditory augmentation: which involves the delivery of sound based augmented via speaker devices (arranged spatially) and haptic augmentation: which involves the delivery of tactile augmentations (touch, pressure or vibrations) via small motors. In mixed reality environments, visual, auditory and haptic augmentations may be used all-together as outputs although, the visual form is more commonly encountered [20]. Auditory and haptic augmentations in mixed reality environments can be used to support learning especially for the visually challenged learners [13].

Up on till a few years ago, mixed reality was considered applicable within certain sectors, the advent of powerful mobile devices such as tablets and smartphones has completely revolutionized mixed reality research and it is now seen as a powerful tool capable of supporting both formal and informal learning in science and engineering [9]. There are already many examples of educational use of mixed reality technology including: the training of operators in specialized processes [15]; training operators in system maintenance [33]; medical training [1]; story telling (Magic Book) [5]; educating learners about cultural heritage, architectural design and urban planning [23]. A mixed reality application for mechanical engineering allows users to interact with a web based 3D model of piston [22] and the augmentation of remote laboratories in electrical engineering [2]; supporting laboratory experiments in electronics [31], power generation [28] and communications engineering [29].

In education, the use of mixed reality applications on mobile devices is driving new frontiers in personalised learning especially in tailoring learning-experience to the individual learner. That is, within a mixed reality environment, in addition to the on-demand access (delivery) to learning objects, a learner could also choose the means and levels of interacting with the learning objects. For example, in the Magic story book, a learner can choose to interact with three dimensional (3D) graphical animations of characters from the story [5]. It is also clear that using learner owned mobile devices also promotes personalisation. Collaborative learning in mixed reality environments is obtained mainly through the shared use of a common viewing device. That is, learners working in small groups participate in the collective use of a single mixed reality tool and informally exchange and share information among themselves as each one had a different viewing angle. An alternative approach is the serial use of a single mixed reality tool, where each learner is responsible for individual use, there is some informal exchange or sharing or passing of hints and other information from one learner to the next. The next section discusses the collaborative use of a pair of mixed reality environments along with the synchronised use of multiple mixed reality tools within a single environment.

3 Collaborative Mixed Reality Environments

The previous section examined existing approaches to collaborative learning in STE disciplines and mixed reality environments. This section presents two additional approaches for collaborative learning within mixed-reality environments based on concepts from High Performance Computing. These approaches consider only the concurrent use of more than one mixed reality environments.

3.1 Paired

Figure 1 shows two mixed reality tools (labelled A and B, respectively) paired for collaborative use. A key requirement is that both mixed reality tools would be very similar in composition, that is using the marker and application concurrently, even if the physical hardware devices are different. That is, A could be a smart phone, while B could be a tablet device. It is clear that the paired environments or tools may be located at great geographic distances as long as the resulting latency is small enough. Within, this paired collaborative environment, once the connection is established between the pair, information about changes in objects resulting from user manipulations (or otherwise) are transferred between them. For example, rotating an object (knob) in A would cause the same knob to rotate in B.

Fig. 1. Paired mixed reality tools/environments

In this approach, collaboration is through direct communication between a pair of mixed-reality environments over a common channel or network. The formatting of messages and subsequent direct exchange of data/information between two entities may be implemented within a mixed reality application as proprietary software code or through the use of third-party libraries. The well-known Message Passing Interface (MPI) libraries in High Performance Computing (HPC) includes basic functions for establishing a point-to-point communication model for the exchange of data between two entities. Apart from MPI or similar tools, there are also standards (e.g. REST) and libraries for data communication that include suitable routines/functions for initializing a communication channel, establishing a connection and performing the transfer of data over a suitable network such as the internet using well-defined formats.

The paired collaborative learning mixed reality environment is well suited for one-on-one joint exploration of objects; guiding and teaching specialized processes such as medial training, etc.

3.2 Broadcast

Moving beyond a paired, one-to-one or point-to-point collaborative learning model, a one-to-many model of communication is required especially during group collaboration as shown in Fig. 2, where, a mixed reality tool (A) is communicating with other tools (B, C, D and E). Similar to the paired collaborative environment, the tools must be very similar in composition. In MPI and similar libraries, one-to-many communications within a common group is typically performed using a broadcast model. That is each entity sends a single message that is received by all other members of the group without a sender individually transmitting the same message to each member entity. The one-to-many model may be extended to a many-to-many situation, where a member can dynamically switch between sending and receiving; that is, acting as a sender broadcasting

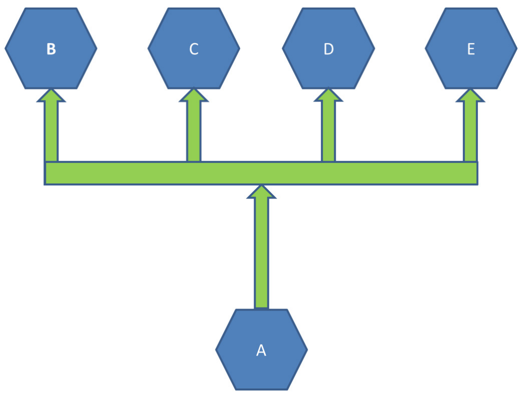

Fig. 2. Broadcast (one to many) mixed reality tools/environments

its message to all other members or acting as recipient receiving messages from other senders.

Consider a group of mixed-reality visualisation tools which are co-located within a room possibly all pointed at the same reference marker. It is expected that each tool presents an independent windowed-view into the mixed-reality environment that is unique based on angular orientation and direction. Using the broadcast approach, a synchronised collaborative learning environment is created where user manipulations performed on any member device that results in changes to objects would be broadcast to all other mixed reality tools in the room. Locating members of the group mixed reality tools at great distances is also possible although there may be some difficulties with compensating for variable round-trip delays or latency that may exist from one location to another.

The synchronised collaborative learning mixed reality environment is well suited for one-on-many group exploration of objects; demonstrating and teaching specialized processes such as medial training, etc. While a many-to-many form may be implemented, it could easily become chaotic.

4 Results

Many users are increasingly exposed to mixed reality technology and environments during day-to-day activities such as using street navigation systems and viewing sporting events on television. There is also a growing availability of mixed reality tools/applications for mobile devices such as smart phones and tablets, where they are deployed and used in a personalised or non-collaborative context.

This section presents results from a questionnaire based study carried out to investigate experiential attitude towards using mixed reality based collaborative environments created from mobile technologies. There were a total of 84 respondents from 5 different STE disciplines as shown in Table 1.

The survey was designed as a set of closed items or questions and responses were collected based on a 5-level Likert scale for analysis after associated exposure to mixed-reality tools/environments (either paired or broadcast) developed using mobile technology. A summary of the collected responses is presented in Table 2.

As shown in Table 2, the respondents who were all learning within traditional classrooms environments (without blended learning) were not very familiar with the academic use of social networks or similar tools. However, they claimed to be more familiar with the academic use of mixed reality tools. The collected data suggests that majority of learners did not find the collaborative environments confusing and also prefer collaborative-work over working in online groups, forums and social networks. This may be attributed to the sharing and exchange of useful information that occurs during collaborative learning and is in line with the findings of other authors including [6,10]. However, it is noted that most of the respondents were familiar with working collaboratively during their laboratory, practical and/or tutorial classes.

Table 1. Profile of the respondents

Demographic profile	Frequency	Percentage (%)
Departments		
Computational Science	13	15.48
Computer Science	1	1.91
Engineering	33	39.29
Mathematics	6	7.14
Physics	25	29.76
Data not provided	6	7.14
Role		
Students	75	89.29
Lecturers	5	5.95
Data not provided	4	4.76
Student level		
1st year	33	39.29
2nd year	5	5.95
3rd year	14	19.44
Masters	16	19.05
Ph.D	4	4.76
Data not provided	12	14.29
Age range		
16–20	36	42.86
21–24	17	20.24
25–29	12	14.29
30–35	10	11.90
Over 35	5	5.95
Data not provided	4	04.76

Table 2. Summary table of responses

Questionnaire item	Yes (%)
Do you participate regularly in on-line group/forums/social networks and discussion sites?	27.38
Are you familiar with mixed reality environments?	30.37
Do you find the mixed reality environments confusing?	19.52
Did you like the mixed reality collaborative environments?	72.62

The study presented here was limited in scope as respondents were asked to only consider academic use of on-line tools and also learner preference between paired and broadcast collaborative environments was not investigated.

4.1 Discussion

Traditionally, mixed reality environments created with mobile technology are non-collaborative in nature as they are designed to by used by a single individual. As discussed in Sect. 2, some level of collaborative use of a single mobile device by two or more individuals is possible but quite limited as one learner typically performs all the tasks/actions while others play a mostly passive role. The paired and broadcast mixed reality collaborative environments presented in Sect. 3 support the synchronous use of a mixed reality application on multiple devices geographically distant from one-another for creating a collaborative environment. Conceptually the resulting environments are similar to well-known collaboration concepts such as the use of study-partner and discussion groups, respectively. The discussed paired environment is also suitable for use in a one-on-one instructor-learner collaboration and provides for joint visualisation and manipulation of objects. While, the broadcast environment is more suited for a one-to-many (instructor-to-group) collaboration. Here, the manipulations of objects on the primary device are replicated to all other devices.

Augmented Reality (AR) supplements reality through displaying useful information, not directly detected by the senses of a user, helping the user to perform real-world tasks and facilitating the understanding of complex scenarios [4]. It is used to describe an environment where the physical world is enhanced by adding computer-generated objects using computer vision methods to make them appear as if they co-exist in the same dimension [32]. It is crucial for learners to engage in experimentation in science and engineering. There has been the question of discerning the best approach, utilizing either the physical or virtual laboratories. Various studies have shown that students who conducted both physical and virtual experiments outperformed those in the physical-alone and virtual-alone conditions, capitalising on the benefits of each approach [8,11,17,18,21,26,35]. The virtual laboratory settings test and consolidate conceptual knowledge while the physical laboratory settings test and consolidate abilities relating equipment handling and use.

In a recent study [19], Augmented and Virtual Reality, along with adaptive technologies in learning and maker-spaces have been shown to be among the list of trends reflecting the mixing of realities experimented in aspects of society, such as communication and entertainment. Current efforts could be directed at improving current markers used in AR and the development of markerless systems portability and enhanced user experience.

5 Conclusion

This paper on collaborative learning in mixed reality environments presents two new approaches for moving beyond a basic single environment sharing model.

The first approach shows the use of a pair of geographically distant mixed-reality environments for remote collaborative learning, while the second approach show multiple (independent) mixed-reality tools synchronised for co-located group work/learning. To our knowledge, this work is unique in relating collaborative learning on mixed-reality environments to established message passing concepts/systems from High Performance Computing (HPC). The collected data from survey of learners suggests a clear preference for collaborative experience compared to well-known online groups, forums and social networks.

We note that in education, use of the proposed mixed-reality platform presents a challenge for teachers and instructors. As stated, learning within technology creates a pedagogical shift that requires teachers to think about measuring outcomes in non-traditional ways [14]. This extends from acceptance and inclusion into their everyday practice, right through to assessment and other pedagogical issues. This makes it necessary to evaluate students' learning gains and propose adequate mechanisms for assessment.

The use of mixed reality in such environments has the potential to enhance level of interaction of learners on any of these platforms and increase collaboration for increased understanding of concepts and completion of projects and tasks.

References

1. Albrechta, U., Nolla, C., von Jan, U.: Explore and experience: mobile augmented reality for medical training. In: Lehmann, C.U., Ammenwert, C., Nahr, C. (eds.) MEDINFO 2013: Studies in Health Technologis and Informatics, vol. 192, pp. 382–386. IMIE & IOS Press, Copehegen (2013)
2. Andujar, J.M., Mejias, A., Marquez, M.A.: Augmented reality for the improvement of remote laboratories: an augmented remote laboratory. IEEE Trans. Educ. **54**(3), 492–500 (2011)
3. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., MacInTyre, B.: Recent advances in augmented reality. IEEE Comput. Graph. Appl. **21**(6), 34–47 (2001)
4. Azuma, R.T.: A survey of augmented reality. Presence-Teleoperators Virtual Environ. **6**(4), 355–385 (1997)
5. Billinghurst, M., Kato, H., Poupyrev, I.: The MagicBook - moving seamlessly between reality and virtuality. IEEE Comput. Graph. Appl. **21**(3), 6–8 (2001)
6. Broman, D., Sandahl, K., Baker, M.A.: The company approach to software engineering project courses. IEEE Trans. Educ. **55**(4), 445–452 (2012)
7. Canessa, E., Zennaro, M.: A mobile science index for development. Int. J. Interact. Mob. Technol. **6**(1), 4–6 (2012)
8. Climent-Bellido, M.S., Martnez-Jimnez, P., Pontes-Pedrajas, A., Polo, J.: Learning in chemistry with virtual laboratories. J. Chem. Educ. **80**(3), 346 (2003)
9. Davidsson, M., Johansson, D., Lindwall, K.: Exploring the use of augmented reality to support science education in secondary schools. In: Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education, pp. 218–220. IEEE Computer Society (2012)
10. Davis, C.E., Yeary, M.B., Sluss, J.J.: Reversing the trend of engineering enrollment declines with innovative outreach, recruiting and retention programs. IEEE Trans. Educ. **55**(2), 157–163 (2012)

11. de Jong, T., Linn, M.C., Zacharia, Z.C.: Physical and virtual laboratories in science and engineering education. Science **340**(6130), 305–308 (2013)
12. Felder, R.M., Woods, D.R., Stice, J.E., Rugarcia, A.: The future of engineering education II. Teaching methods that work. Chem. Eng. Educ. **34**(1), 26–39 (2000)
13. FitzGerald, E., Adams, A., Ferguson, R., Gaved, M., Mor, Y., Thomas, R.: Augmented reality and mobile learning: the state of the art. In: Specht, M., Sharples, M., Multisilta, J. (eds.) 11th World Conference on Mobile and Contextual Learning (mLearn 2012), pp. 62–69. CEUR, Helsinki (2012)
14. Gardner, M., Elliott, J.: The immersive education laboratory: understanding affordances, structuring experiences, and creating constructivist, collaborative processes, in mixed-reality smart environments. EAI Endorsed Trans. Future Intell. Educ. Environ. **14**(1), e6 (2014)
15. Henderson, S.J., Feiner, S.: Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In: Proceedings of IEEE ISMAR-AMH, pp. 135–144. IEEE (2009)
16. Hosseinzadeh, N., Hesamzadeh, M.R.: Application of project-based learning (PBL) to the teaching of electrical powersystems engineering. IEEE Trans. Educ. **55**(4), 495–501 (2012)
17. Huppert, J., Lomask, S.M., Lazarowitz, R.: Computer simulations in the high school: students' cognitive stages, science process skills and academic achievement in microbiology. Int. J. Sci. Educ. **24**(8), 803–821 (2002)
18. Jaakkola, T., Nurmi, S., Veermans, K.: A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. J. Res. Sci. Teach. **48**(1), 71–93 (2011)
19. Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., Hall, C.: Horizon report 2016: Higher education edition (2016). http://cdn.nmc.org/media/2016-nmc-horizon-report-he-EN.pdf. Accessed 9 Jul 2017
20. Kilby, J., Gray, K., Elliott, K., Waycott, J., Sanchez, F.M., Dave, B.: Designing a mobile augmented reality tool for the locative visualization of biomedical knowledge. In: Lehmann, C., Ammenwert, C., Nahr, C. (eds.) MEDINFO 2013: Studies in Health Technologis and Informatics, vol. 192, pp. 652–656. IMIE & IOS Press, Copenhagen (2013)
21. Kollffel, B., de Jong, T.: Conceptual understanding of electrical circuits in secondary vocational engineering education: combining traditional instruction with inquiry learning in a virtual lab. J. Eng. Educ. **102**(3), 375–393 (2013)
22. Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P., Basu, A., Lister, P.F.: Web3D and augmented reality to support engineering education. World Trans. Eng. Technol. Educ. **3**(1), 11–14 (2004)
23. Loscos, C., Widenfeld, H.R., Roussou, M., Meyer, A., Tecchia, F., Drettakis, G., Gallo, E., Martinez, A.R., Tsingos, N., Chrysanthou, Y., Robert, L., Bergamasco, M., Dettori, A., Soubra, S.: The create project: mixed reality for design, education, and cultural heritage with a constructivist approach. In: The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, pp. 282–283. IEEE (2003)
24. Macias, J.A.: Enhancing project-based learning in software engineering lab teaching through an e-portfolio approach. IEEE Trans. Educ. **55**(4), 502–507 (2012)
25. Milgram, P., Takemura, H., Utsumi, A., Kishino, F.: Augmented reality: a class of displays on the reality-virtuality continuum. Telemanipulator Telepresence Technol. **2351**, 282–292 (1994). SPIE

26. Olympiou, G., Zacharia, Z.C.: Blending physical and virtual manipulatives in physics laboratory experimentation. In: Topics and Trends in Current Science Education, January 2014
27. Onime, C., Uhomoibhi, J.: Engineering education in a developing country: experiences from Africa. In: 2012 15th International Conference on Interactive Collaborative Learning (ICL), Villach, Austria, pp. 1–3 (2012)
28. Onime, C., Uhomoibhi, J., Pietrosemoli, E.: An augmented virtuality based solar energy power calculator in electrical engineering. Int. J. Eng. Pedagogy **5**(1), 4–7 (2015)
29. Onime, C., Uhomoibhi, J., Radicella, S.: MARE: mobile augmented reality based experiments in science, technology and engineering. In: Restivo, M.T.R., Cardoso, A., Lopez, A.M. (eds.) Online Experimentation: Emerging Technologies and IoT, pp. 209–227. IFSA Publishing, Barcelona (2015)
30. Onime, C., Uhomoibhi, J., Wang, H.: Mixed reality cubicles and cave automatic virtual environment. In: The 15th International Conference on Ubiquitous Computing and Communications (IUCC 2016), Grenada, Spain, pp. 1–8. IEEE Conference Publishing Services, December 2016
31. Onime, C., Uhomoibhi, J., Zennaro, M.: A low cost implementation of an existing hands-on laboratory experiment in electronic engineering. Int. J. Eng. Pedagogy **4**(4), 1–3 (2014)
32. Pastoor, S., Conomis, C.: Mixed Reality Displays. Wiley, New York (2006). pp. 261–280
33. Schwald, B., de Laval, B.: An augmented reality system for training and assistance to maintenance in the industrial context. In: Proceedings of International Conference on Computer Graphics, Visualization, Computer Vision, pp. 425–432. IEEE Computer Society (2003)
34. Takemata, K., Nakamura, S., Minamide, A.: Design of a lifelong learning program with regional collaboration: intership for high school students. In: Aung, W., Ilic, V., Moscinski, J., Uhomoibhi, J. (eds.) Innovations 2011: World Innovations in Engineering Education and Research, pp. 3–11. iNEER, Potomac (2011)
35. Zacharia, Z.C., Olympiou, G., Papaevripidou, M.: Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. J. Res. Sci. Teach. **45**(9), 1021–1035 (2008)