Evaluating System Usability and Acceptance of a Quiz Based Augmented Reality Interaction for Learning Solutions of Electrical Motor

Yih Bing Chu[1], Yong Cai Zhang[1,2,*], and Hor Yeng Wong[1]

[1]Department of Electrical and Electronics Engineering, FETBE, UCSI University, Kuala Lumpur, Malaysia
[2]College of Artificial Intelligence, Dongguan City University, Guangdong, China
Email: Chuyb@ucsiuniversity.edu.my (Y.B.C.); 1052524930@qq.com (Y.C.Z.); horyeng@me.com (H.Y.W.)
*Corresponding author

Manuscript received June 17, 2024; revised July 8, 2024; accepted July 29, 2024; published September 19, 2024

***Abstract*—Learning of electrical motor is difficult as it's understanding requires fundamental knowledge of multidisciplinary concepts such as mechanical, electrical and electromagnetism. At the same instance, the number of enrollment for students pursuing engineering programs in the higher education is declining. In response to this, there is a need to come out with a solution to stimulate the interest of students and improve their confidence in learning the subjected materials. This study proposed the development of an innovative Augmented Reality (AR) interaction environment for learning solutions related to basic principles of electrical motor operations. The AR system is built in Android platform for smartphone suitable to be placed into a virtual reality headset. The corresponding scenarios causing malfunction of the motor are projected as quiz scenario to the participants of the study. The participants are required to come up and select the appropriate solution to identify and troubleshoot the issues based on the appearance and movement of the virtual motor. The interactions between the participants and the developed system are made through vision capturing of the finger movement of the participants using the in-built smartphone camera. Based on the results, the proposed AR system is able to stimulate the interest of the users and applicable to enhance their learning experience and problem analysis skill through the outlined features. Overall, the developed system demonstrated much potential for enhancing the learning experience of engineering education and to attract students to involve in STEM related activities.**

***Keywords*—Augmented Reality (AR), electrical motor, learning solutions, quiz-based scenarios, virtual interaction, usability**

I. Introduction

Due to the emergence of digital technology, many institutions have shifted their attention to utilizing the existing digital tools in transforming educational practice. Based on some researchers, the application of digital technologies improved the quality of teaching and reduced the operational cost of learning system [1–3]. For technical courses that require the use of hardware and machinery, the laboratory can be conducted through the digital tools for experiential learning and acquisition of relevant hands-on skill [4–6]. In addition, students exposed under this digital learning environment are found to be more motivated and engaged in learning [7].

In higher education, the number of students who pursue further studies in science and engineering programs are slowly decreasing. The down-steep is linked to negative self-perception of the students towards the courses and the financial aftermath followed by the recent pandemic [8]. Researchers have identified that through proper learning environment, students' awareness and interest on STEM courses can be established. Subsequently, this will promote the interest of students and inspire them to pursue their study in STEM related fields [9–10]. Based on this, we can conclude that through the introduction of specific stimuli, the user's perception towards the acceptance of the technology will also be influenced. Especially for engineering studies, both the cognitive and practical domains are weighted similarly during the gaining of technical knowledge.

Recently augmented reality (AR) has been applied in education institutes to guide students in their learning. The AR technology overlaps virtual information onto real world, thus provides much seamless interactivity to the users. Under this context, the conceptual knowledge of the subjected content is projected as a digital representation, subsequently reducing much cognitive load of the users to visualize the overall processes. In the education field, several applications have been developed using AR technology in conducting STEM related lessons such as biology, chemistry and physic [10–12]. For engineering application, classes incorporated with AR are found to improve the motivation of students, enrich the learning experience and stimulate their self-acceptance towards the adoption of the technology as the learning platform [13–15].

AR technology serves as an alternative platform for simulation study of related engineering applications. The technology as one of the technology pillars of Industry 4.0 has already made an impact in various simulation guidance, operation training and teaching involving constant interaction and active engagement with users [16]. Majority of the research agree to the influence of AR in stimulating the interest of users and promotes the acquisition of knowledge easily in much engaging fashion.

Hence, this paper proposed to develop an AR system to promote the learning of technical knowledge in engineering study. As a means of engaging stimuli, the AR system will relate a series of quiz like scenarios to the engineering content which require the students to identify the problem and determine the solution to troubleshoot the error interactively. A scoring module is then displayed on the projected scene to allow the students to reflect their achievements and understandings on the addressed problem. Throughout the study, usability of the AR system and the motivation of the students will be examined to evaluate the outcome of the research.

doi: 10.18178/ijiet.2024.14.9.2160

II. Literature Review

In recent years, augmented reality has been increasingly applied in education. The corresponding AR application can be packaged into Android platform to support the learning of digital electronics [17]. Based on the reported study, for this type of AR interaction, the schematic layout is projected next to the digital chip to guide students in understanding the connections and operations of the circuit. A similar handheld system has also been applied in identifying resistance value and understanding of finite state machine through AR projections [15, 18]. Based on the study, students are more engaged with the learning process and responded positively towards the adoption of AR in the classroom.

Research has shown that learning environments, particularly involving activities which prompted the response from students, are able to induce the interest of students and keep them attended to the learning process [19, 20]. Students found that learning activities integrated with AR are more interactive, exciting and enjoyable to take part in. Based on the study conducted by [21], students interacting individually with the AR content representing the circuit element are found to learn better the concept of electromagnetism. As a result, they will become more interested and oriented in attending to the subject taught.

Overall, animation of physical structures through 3D visualization in the AR environment has the potential to support constructive engagement and understanding of the students on the topics being delivered [22]. Under this context, students are free to manipulate the input of the system and relate the changes in the behavior of the augmented content to the fundamental concepts of the subject taught. As such, students are consistently interacting with the teaching material in the AR scene and subsequently enhance their learning experience and motivation to learn the course [23].

In addition, AR has also been introduced to conduct basic laboratory [13, 24]. The digital content representation of the hardware and equipment setup is projected onto the AR scene and hence, students can explore the activities more freely without the risk of exposure to unsafe events. Since digital contents are being manipulated, routine maintenance and servicing of the machines are not required. Besides that, AR systems are found to be easier to set up and access using ubiquitous devices such as smart phones. As such, the operational cost for the application and maintenance of the AR system is by far lower compared to the approach in which the conventional method is applied.

The current technology revolution has driven rapid development of highly personalized products manufactured through complicated machine operations. Subsequently, the industry requires highly skilled worker who is well-trained in managing and operating and servicing such machines and equipment. As a result, universities are constantly pushed to ensure the sufficient of STEM professions to meet the industry demand [25]. The introduction of AR technology has significantly changed the landscape of STEM education in recent years. The AR integrated content is designed to visualize complicated concepts and guide the engineering design process [26] commonly encompassed in STEM education. Especially during the recent pandemic, researchers have extensively applied AR technology to support lesson delivery. The AR assisted education improved the critical thinking and practical skills of students [27], however, there is no indication of the improvement in learning motivation brought by AR to the students as mentioned in the previous studies [28]. In view of this, researches should be carried out to continuously develop competent AR system capable to motivate students to learn and commit in STEM related courses.

Based on the literatures, to suit the variety interests of students, a general multidisciplinary system such as motor is chosen as the subjected learning materials. To actively engage the student in the learning process, a few scenarios where the motor is experiencing malfunction will be projected onto the AR scene. The failure experienced is distinct as per the projected scenarios in which the students are prompted to identify the problem and suggest the corresponding solution based on the behavior of the motor. Through introduction of animating object, users can relate better the underlying concepts of the motor operation to the addressed issues. In the proposed system, students can provide their feedback through interacting with the virtual buttons outlining the choices of answer which are readily displayed in the AR scene. Since the students are consistently prompted for interaction with the system, their attention to the learning process can be maintained accordingly. The correct answer will be displayed after each selection and upon completion, a final score value will be projected to reflect the overall achievement and competency of the students for their understanding on the topic. Finally, collective feedback by means of short discussion and surveys to the students are gathered to evaluate the outcome of the study.

III. Materials and Methods

A. Participants and Procedures

There are about 41 participants who voluntarily took part in this study. The participants are aged between 18 to 20 years old and are currently studying in a pre-university program or in their freshman year (science stream). All the participating students do not have any prior experience in applying similar AR system in their current studies.

The motor will be projected once the students pointed their headset in direction to the image target. The students need to identify the problem and solution to the quiz based on the appearance or movement of the projected motor. To proceed to the next scenario, they are required to select the correct answer out from the projected choices next to the motor. The choices are then confirmed once the students point their hand to the virtual buttons representing their choices of answer. For each of the choices made, the corresponding correct answer will be displayed onto the scene prior to the next scenario. Once all the scenarios have been reached, a final score is then displayed on the AR scene to reflect their achievement.

B. AR Application

In this study, the AR application is constructed using Unity 3D with Vuforia Engine development kit. The application eventually will be packaged in Android platform to suit installation in smartphone which is then placed into a virtual reality headset for actual deployment. During the development, a specific image target is set as the ground plane to project the augmented contents. As such once the vision zone of the headset is directed on the target image, the projected motor accompanied with the virtual buttons will be oriented on top of the image.

Fig. 1 shows the image used as the projection target of the augmented contents. The dotted regions are the feature point generated by the Vuforia Target Manager, a web-based development portal for the AR application built with Vuforia Engine. It is important to note that the virtual buttons should be designated on the generated feature points so that the hand interaction of users with the buttons can be captured and recognized by the AR system. Fig. 2 shows the placement of the augmented contents on the image target in the development scene of Unity 3D.

Fig. 1. The target image for AR projection. Left: Original version. Right: Feature points shown represented with dotted point.

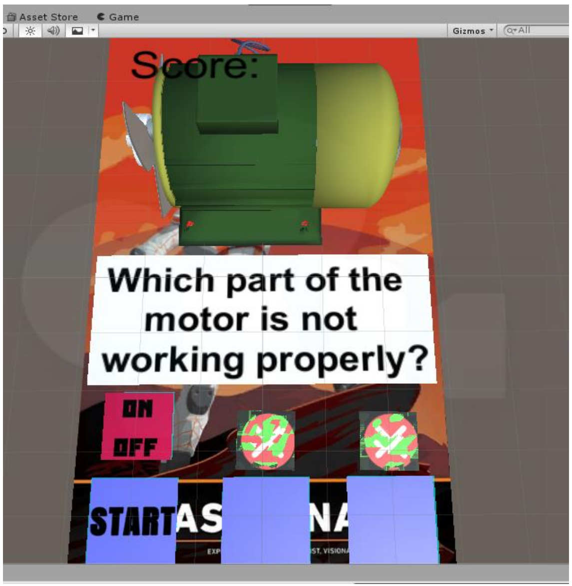

Fig. 2. The scene view of the game design.

There are four virtual buttons being utilized in this work. The virtual button just below the augmented question display is meant to turn on or off the motor. The choices of answer are projected onto the remaining buttons accompanied by the question or quiz displayed just below the motor. The selection of the corresponding solutions and the problems experienced by the motor is done by hand manipulation from the user onto the projected answer. At the same instance, the camera from the smartphone which is used to project the virtual motor is programmed to track the interaction of the user on the projected virtual button. Once the selection is successfully tracked or recognized, the correct answer will be highlighted with a tick symbol represented by the corresponding virtual button. The appearance and rotation speed of the motor varies depending on the addressed quiz and that students can observe the changes made by the correct choices to the behavior of motor after the interaction made. The following question will then be projected together with the new sets of choices till the completion of the quiz which sees the score percentage representing the number of questions being answered correctly. Fig. 3 and Fig. 4 show the AR projection on smartphone display and students engaging in the AR activities respectively.

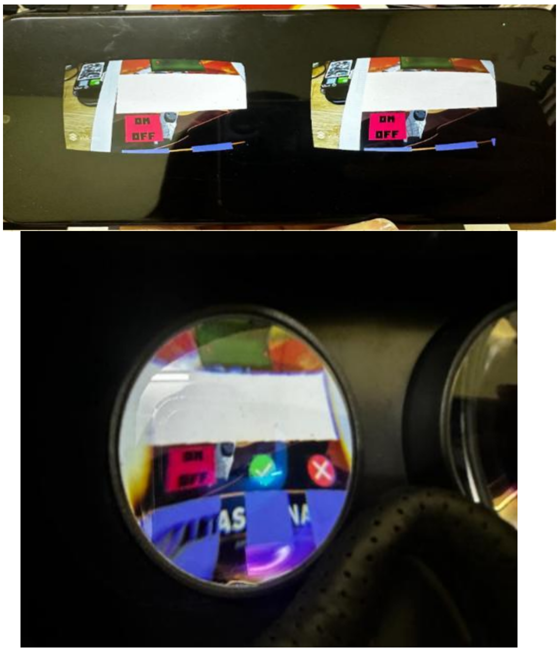
Fig. 3. AR projection on the smartphone display. Top: Plain view without the virtual reality headset. Below: Placed into the virtual reality headset.


Fig. 4. Student engaged in AR system.

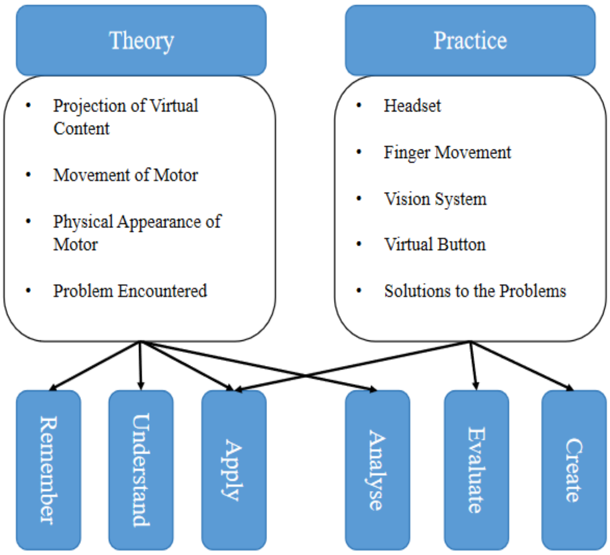

Fig. 5. Typical linkage of the theoretical framework of the AR technology to learning outcome of engineering education.

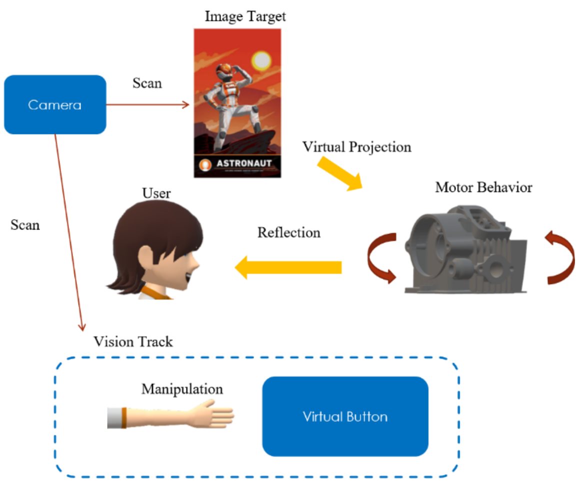

Fig. 6. Overall System Implementation of the developed AR tool.

The proposed AR system provides an interactive and personalized learning to the students. The projected problems experienced by the virtual motors are reflection of what commonly encountered after long servicing period especially in the absence of proper maintenance. The students will build up their problem solving skill through close observation (analyse) and relation on the operation of the motor to the fundamental physics such as friction, electromagnetism and work done (remember). At this instance, the students are given the role of learner, to gather all the relevant points (analyse) and finalize the perception to the intended quiz (evaluate). The physical prototype accompanied with virtual button triggering (apply) provided them the opportunity to experience laboratory-like experiment which in many ways similar to the mandatory practical assessment encompassed in most STEM courses. Based on these workaround, the students gradually study the movement and theoretical concepts of the working motor (understand) and subsequently enable them to grasp the basic understanding of the learning materials and exhibit interest to learn the related subject. However, since the students are not creating any products, the AR technology could incorporate features prompting them to come up with new solving idea in order to meet the subjected learning domain (create). Fig. 5 and Fig. 6 shows the relation on the theoretical framework of the AR system to typical learning outcome of engineering education and the overall system implementation of the AR tool respectively.

C. *Survey*

There are two important metrics to explore in this work:

1) Interest or motivation of students
2) Usability of the AR system

As mentioned in the previous section, the objective of the research lies in determining should the proposed system able to instill the interest of students. In this study, a reduced version of Keller's Instructional Materials Motivation Survey [11, 13, 29, 30] is used to measure the interest of students after completing the activities. Table 1 shows the 12 items under the reduced version of the motivation survey.

Table 1. Reduced version of Keller's instructional materials motivation survey

No	Questions (Motivation)	Domain
1	The quality of the AR application is helpful seizing my attention.	Attention
2	The way the information is interfaced on the AR application helped hold my attention.	
3	The variety of contents helped hold my attention on the user instructions.	
4	It is clear to me how the content of this learning material is connected to the things that I knew.	Relevance
5	The content and presentation style in this lesson impress me that the content is worth knowing.	
6	The content of this work will be helpful to me.	
7	I was confident that I could learn the content after working on this lesson	Confidence
8	A moment after working on this lesson, I was confident that I would be able to pass a test related to it.	
9	The organization of the content convinced me that I would learn this material.	
10	I would like to learn more about the related topics of this subject after feeling such enjoyment working on the lesson.	Satisfaction
11	I truly enjoyed working on this lesson.	
12	It was pleasurable to work on this well-designed lesson.	

On the other hand, a general survey addressing the technical difficulty encountered by the students is also implemented followed by a closure interview to outline the overall learning experience of the students using the AR application. Table 2 shows the questionnaire for the technical difficulty surveys.

Table 2. Questionnaire for the technical difficulties survey

No	Questions (Technical Difficulties)
1	Is it easy to operate the AR application?
2	Is the Motor behavior similar to the real motor?
3	Do you find the buttons on the interface to be appropriate and easy to manipulate?
4	Do you find it easy to control using mobile device and headset?
5	Do you find it easy to distinguish between real world and virtual world?
6	Does having devices with augmented content such as headset improves the AR experience?
7	Are there any hardware or software issue upon using it?
8	Is it easy to complete the activity?

All the surveys implemented in this work are addressed based on Likert-scale ranged from 1 (strongly disagree) to 5 (strongly agree) and measured based on the average score of the collected feedbacks. Then, a reliability test based on Cronbach's alpha is implemented to evaluate the reliability of the results.

Fig. 7 shows the overall process flow chart of the conducted study.

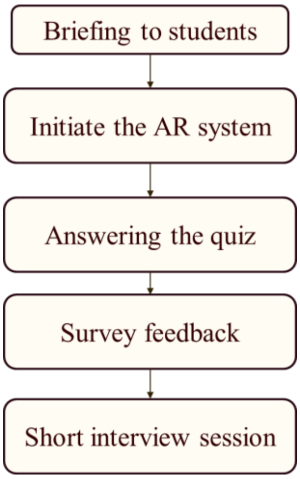

Fig. 7. Overview process flowchart of the study.

IV. Result and Discussion

Table 3 shows the result of the motivation survey. Based on the results, all the dimensions of the motivation survey recorded an average value of about 4.0 indicating high or above average motivation level. For the attention domain, the average score is about 4.033 indicating that the participants attended the AR activities. For relevance domain, an average score of 4.098 is recorded which implies the participants are in overall in agreement that the AR content is relevant to their interests. Lastly, most of the students expressed confidence in using the AR system and are satisfied with the learning platform as indicated with the mean score of 3.951 and 4.024 respectively.

Table 3. The survey results on the motivation of the participants

Domain	Mean	Maximum	Minimum
Attention	4.033	4.098	3.976
Relevance	4.098	4.220	4.024
Confidence	3.951	4.220	3.756
Satisfaction	4.024	4.171	3.878

Table 4 shows the results of the technical difficulty survey. Overall, students found no issues in operating the AR system (Mean = 3.707). The students were able to perceive the operation of the augmented motor (Mean = 3.878) with ease. No severe difficulties were encountered while interacting with the virtual buttons (Mean = 3.463) using the headset (Mean = 3.463). Furthermore, the augmented contents can also be easily distinguished by the students (Mean = 3.634) with much pleasant experience (Mean = 4.073). The students were able to engage the AR system without any technical issues (Mean = 3.219) and complete the activities smoothly (Mean = 4.219).

The Cronbach's alphas for the surveys are shown in Table 5. Based on the result, the alpha coefficients for all the surveys are around or higher than 0.8 suggesting that the response given by the participants are internally consistent and considered accepted [13, 31].

Table 4. The survey results on the technical difficulties encountered by the participants

No	Questions (Technical Difficulties)	Mean
1	Is it easy to operate the AR application?	3.707
2	Is the Motor behavior similar to the real motor?	3.878
3	Do you find the buttons on the interface to be appropriate and easy to operate?	3.463
4	Do you find it easy to control using mobile device and headset?	3.463
5	Do you find it easy to distinguish between real world and virtual world?	3.634
6	Does having devices with augmented content such as headset improves the AR experience?	4.073
7	Are there any hardware or software issue upon using it?	3.219
8	Is it easy to complete the activity?	4.219

Table 5. Internal consistency of the surveys using Cronbach's alpha

Survey	Cronbach's Alpha
Motivations	0.94
Technical Difficulties	0.78

Based on the results, it can be concluded that the AR system is able to stimulate the interest of students accordingly. However, some of the questionnaires in the technical difficulties such as hardware/software, buttons and control recorded much lower score compared to the overall feedback received. A short interview or discussion session has been conducted after completing the activities to understand the said observations. Firstly, some students addressed that they are not able to undo the selections of answers when they accidentally triggered the button interactions. Since the manipulation of the virtual buttons only accept one time response, the selections made by the students are considered final. Moreover, due to the smaller placement gap between the virtual buttons, the students need to be extra cautious when interacting with the system to prevent triggering false responses. As an improvement, undo features and confirmation button can be introduced to allow students to modify the selection and finalize the chosen answer before proceeding to the next question. Studies on the effect of buttons separation on the user interaction and the mental domain shall be explored as well in the following research.

On the other hand, focus of the headset can be altered to accommodate users with different vision capability, but limited to the myopia (nearsightedness) user. For users with hyperopia (farsightedness) conditions, they are still required to put on their spectacles together with the headset and subsequently contribute to the discomfort usage. In addition, there are no cases of simulation sickness reported suggesting that the proposed system is suitable for long term engagement from the users. Since all the participants do not possess any prior experience with AR, they started to respond to the activities quite slowly when it just began. They suggested that the headset can be omitted in the future by just simply pointing the smart phone camera onto the image target. Other than that, all the students responded positively to the proposed AR systems. They found out that it is very enjoyable and refreshing using the AR application as the learning platform. In addition, they are captivated by the quiz-based scenarios and expressed interest in learning the electrical motor operations.

As mentioned earlier, this work focuses on exploratory research on the application of the proposed AR system and the design of the study only limited to basic content. As such, the number of participants are only kept at around 40 to 50 just in aim to satisfy the survey requirement and to confirm the methodology of study [32, 33]. Nevertheless, to reflect on the long-term assessment of the system, a larger pool of participants typically close to 100 under a longer period of observation. Besides that, more in-depth, with a larger number of participants, large scale based survey study involving a series of trials can be conducted for example cognitive effort, gender variation, universal usability test for disabled user, influence to the study outcome of pre-tests and post-tests results and so on as future endeavours to the current research. For this case, instead of the descriptive statistic and Cronbach's alphas, for rigorous method such as t-tests and ANOVA involving parametric assumptions would be beneficial. It is also worth noting that, in view with the small scale of surveys and sample sizes that we have collected, it is still too soon to generalize the study and standardize the related application for practical inclusion into the syllabus at this stage. Hence, more specific scope and technical requirements are still needed to the feasibility of the study in the future.

Overall, the proposed AR system provided an interactive learning experience to the students. The action of relating the physics concepts of the electrical motor to selection of virtual button representing the answer to the quiz shaped the knowledge transfer from the digital content to the reflective learning of students in real world. As said earlier, the quiz subjected in the developed application addresses the actual problem and solution commonly encountered in the industry setting especially concerning the maintenance and servicing operation of electrical machine. Such experience involves cyclical process of observation, analysis, reflecting, thinking and triggering the system response resembling the concepts of experiential learning. Subsequently, the practical experience and theoretical knowledge gained from the use of the AR tools fostered a connectivism learning environment aim to improve the scientific literacy of students. The unique innovation of our system lies on the interactive virtual button interaction to find possible solution to the quiz revolve around the augmented virtual motor. The results also show positive acceptance of the students in terms of usage and learning experience. Unlike what being addressed in the previous study, our system manages to impress and captivate the student in learning the subjected content evaluated based on the feedback given in the motivation survey. The setup of AR is less expensive and affordable compared to purchasing the actual machine for the study. As such, in the future, should the AR approach be officially standardized and employed, the tuition fee inclusive of maintenance of the actual machine can be lessen to relief the financial burden of students and may subsequently assist in boosting the intake of students. All in all, it can be concluded that the learning experience through AR is positive, and the students are motivated to the content introduced.

V. Conclusion

This study proposed the development of an AR system to stimulate the interest of students in studying engineering materials. A series of quiz-based scenarios has been implemented to test the understanding of students on the operation of motor in which they need to identify the corresponding problems and solutions based on the appearance and movement of the augmented motor. Based on the results, all the students have responded positively to their learning experience with the constructed AR. The students found that the AR system is very interactive and are motivated in learning the materials. Some limitations and future improvements are identified accordingly. First, to accommodate users with various visibilities, the headset can be omitted by simply projecting the camera onto the image target. Second, an undo feature can be implemented in case the students accidentally selected a wrong answer. We plan to include more quiz-based scenarios covering much wider engineering topics to attract more students to use the AR system. Besides that, the effect of buttons design and separation on user interaction and the mental domain will be explored in-depth in the future study.

Overall, the proposed system has provided a unique and interactive hands-on experience to the students. The AR application enables real-time visualization and interaction with complex engineering concepts. Through digital representation of the physical object, students can conduct the work without the risk of exposure to safety hazards and in addition downtime due to maintenance of the machines can be omitted. Subsequently, this will open up to possible opportunity in establishing remote classroom for distant learning. As such, we expect to see the continuous development of AR in deriving a personalized learning experience suitable to be integrated with the current syllabus.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yih Bing Chu conducted the research, designed the experiments, programmed the system, analyzed the results and prepared the manuscript. YongCai Zhang made the research proposal, drafted the coding, prepared the materials, reviewed the work and proofread the paper. Hor Yeng Wong assisted in conducting the research and preparing the manuscript, located volunteering participants and collected the feedback. All authors had approved the final version.

Funding

This work is supported by Engineering Construction Project of Guangdong Province of Teaching Quality and Teaching Reform in Undergraduate Universities in 2021 with No. YueJiaoGaoHan [2021] No.29.

Acknowledgment

The authors would like to express their gratitude to all the participants involved in the study.

References

[1] A. Andersson and Å. Grönlund, "A conceptual framework for e-learning in developing countries: A critical review of research

challenges," *The Electronic Journal of Information Systems in Developing Countries*, vol. 38, no. 1, pp. 1–16, 2009.

[2] T. Unwin, B. Kleessen, D. Hollow *et al*., "Digital learning management systems in Africa: Myths and realities," *Open Learning*, vol. 25, no. 1, pp. 5–23, 2010.

[3] F. P. Tulinayo, P. Ssentume, and R. Najjuma, "Digital technologies in resource constrained higher institutions of learning: A study on students' acceptance and usability," *International Journal of Educational Technology in Higher Education*, vol. 15, no. 36, 2018. https://doi.org/10.1186/s41239-018-0117-y

[4] R. Younes and D. Bairaktarova, "ViTA: A flexible CAD-tool-independent automatic grading platform for two-dimensional CAD drawings," *The International Journal of Mechanical Engineering Education*, 030641902094768, 2020. https://doi.org/10.1177/0306419020947688

[5] N. Jovanović, S. N. Stamenković, D. Miljković, and P. Chakraborty, "ComVIS—Interactive simulation environment for compiler learning," *Computer Applications in Engineering Education*, 2021. https://doi.org/10.1002/cae.22456

[6] E. Campos, I. Hidrogo, and G. Zavala, "Impact of virtual reality use on the teaching and learning of vectors," *Front. Educ*., vol. 7, 965640, 2022. doi: 10.3389/feduc.2022.965640

[7] K. Sharma, M. Giannakos, and P. Dillenbourg, "Eye-tracking and artificial intelligence to enhance motivation and learning," *Smart Learning Environment*, vol. 7, no. 13, 2020. https://doi.org/10.1186/s40561-020-00122-x

[8] B. Kennedy, M. Hefferon, and C. Funk. (August 2020). Half of Americans think young people don't pursue STEM because it is too hard. Pew Research Center. [Online]. Available: https://www.pewresearch.org/fact-tank/2018/01/17/half-of-americans-think-young-people-dont-pursue-stem-because-it-is-too-hard/

[9] T. Roberts, C. Jackson, M. J. Mohr-Schroeder *et al*., "Students' perceptions of STEM learning after participating in a summer informal learning experience," *International journal of STEM Education*, vol. 5, no. 35, 2018. https://doi.org/10.1186/s40594-018-0133-4

[10] C. Weng, S. Otanga, S. M. Christianto and R. J.-C. Chu, "Enhancing students' biology learning by using augmented reality as a learning supplement," *Journal of Educational Computing Research*, vol. 58, no. 4, pp. 774–770, 2020. https://doi.org/10.1177/0735633119884213

[11] M. Tomara and D. Gouscos, "A case study: Visualizing coulomb forces with the aid of augmented reality," *Journal of Educational Computing Research*, vol. 57, no. 7, pp. 1626–1642, 2019. https://doi.org/10.1177/0735633119854023

[12] C. Macariu, A. Iftene, and D. Gîfu, "Learn chemistry with augmented reality," *Procedia Computer Science*, vol. 176, pp. 2133–2142, 2020. https://doi.org/10.1016/j.procs.2020.09.250

[13] Y. B. Chu, "A mobile augmented reality system to conduct electrical machines laboratory for undergraduate engineering students during the COVID pandemic," *Education and Information Technologies*, vol. 27, no. 1, pp. 8519–8532, 2022. https://doi.org/10.1007/s10639-022-10987-9

[14] N. Arulanand, A. R. Babu, and P. K. Rajesh, "Enriched learning experience using augmented reality framework in engineering education," *Procedia Computer Science*, vol. 172, pp. 937–942, 2020. https://doi.org/10.1016/j.procs.2020.05.135

[15] F. Reyes-Aviles and C. Aviles-Cruz, "Handheld augmented reality system for resistive electric circuits understanding for undergraduate students," *Computer Applications in Engineering Education*, vol. 26, no. 3, pp. 602–616, 2018. https://doi.org/10.1002/cae.21912

[16] J. Lu, C. S. Yu, and C. Liu, "The effects of augmented reality on student engagement, knowledge retention, and academic achievement," *Journal of Educational Technology & Society*, vol. 22, no. 2, pp. 1–13, 2019

[17] C. Avilés-Cruz and J. Villegas-Cortez, "A smartphone-based augmented reality system for university students for learning digital electronics," *Computer Applications in Engineering Education*, vol. 27, no. 3, pp. 615–630, 2019. https://doi.org/10.1002/cae.22102

[18] M. Nadeem, M. Lal, J. Cen, and M. Sharsheer, "AR4FSM: Mobile augmented reality application in engineering education for finite-state machine understanding," *Education Sciences*, vol. 12, no. 8, p. 555, 2022. https://doi.org/10.3390/educsci12080555

[19] C. Boletsis and S. McCallum, "The table mystery: An augmented reality collaborative game for chemistry education," in *Serious Games Development and Applications*, M. Ma, M. F. Oliveira, S. Petersen, and J. B. Hauge (Eds.), Berlin, Germany: Springer, vol. 8101, 2013

[20] S. Cai, F. K. Chiang, and X. Wang, "Using the augmented reality 3D technique for a convex imaging experiment in a physics course," *International Journal of Engineering Education*, vol. 29, no. 4, pp. 856–865, 2013.

[21] M. Ibáñez, A. Di Serio, D. Villaran, and C. D. Kloos, "Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness," *Computers & Education*, vol. 71, pp. 1–13, 2014. https://doi.org/10.1016/j.compedu.2013.09.004

[22] Y. Turkan, R. Radkowski, A. Karabulut-Ilgu, A. H. Behzadan, and A. Chen, "Mobile augmented reality for teaching structural analysis," *Advanced Engineering Informatics*, vol. 34, pp. 90–100, 2017. https://doi.org/10.1016/j.aei.2017.09.005

[23] D. Kaur, A. Mantri, and B. Horan, "Enhancing student motivation with use of augmented reality for interactive learning in engineering education," *Procedia Computer Science*, vol. 172, pp. 881–885, 2020. https://doi.org/10.1016/j.procs.2020.05.127

[24] J. L. D. Alfaro, S. Gantois, J. Blattgerste *et al*., "Mobile augmented reality laboratory for learning acid–base titration," *Journal of Chemical Education*, vol. 99, no. 2, pp. 531–537, 2022. https://doi.org/10.1021/acs.jchemed.1c00894

[25] Y.-S. Hsu, Y.-H. Lin, and B. Yang, "Impact of augmented reality lessons on students' STEM interest," *Research and Practice in Technology Enhanced Learning/Research and Practice in Technology Enchanced Learning*, vol. 12, no. 1, Jul. 2016. doi: 10.1186/s41039-016-0039-z.

[26] W. W. Agustina, S. Sumarto, and B. Trisno, "Augmented reality based on stem for supporting science literacy in vocational education," *Journal of Physics. Conference Series*, vol. 1375, no. 1, p. 012088, Nov. 2019. doi: 10.1088/1742-6596/1375/1/012088

[27] Y. A. Alkhabra, U. M. Ibrahem, and S. A. Alkhabra, "Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program," *Humanities & Social Sciences Communications*, vol. 10, no. 1, Apr. 2023. doi: 10.1057/s41599-023-01650-w

[28] W. Cao and Z. Yu, "The impact of augmented reality on student attitudes, motivation, and learning achievements—a meta-analysis (2016–2023)," *Humanities & Social Sciences Communications*, vol. 10, no. 1, Jun. 2023. doi: 10.1057/s41599-023-01852-2

[29] J. M. Keller, "Development and use of the ARCS model of instructional design," *Journal of Instructional Development*, vol. 10, pp. 2–10, 1987. https://doi.org/10.1007/BF02905780

[30] J. S. Keller and K. Suzuki, "Learner motivation and e-learning design: A multinationally validated process," *Journal of Educational Media*, vol. 29, no. 3, pp. 229–239, 2004. https://doi.org/10.1080/1358165042000283084

[31] K. S. Taber, "The use of Cronbach's alpha when developing and reporting research instruments in science education," *Research in Science Education*, vol. 48, pp. 1273–1296, 2018. https://doi.org/10.1007/s11165-016-9602-2.

[32] I. Radu, X. Huang, G. Kestin, and B. Schneider, "How augmented reality influences student learning and inquiry styles: A study of 1-1 physics remote AR tutoring," *Computers and Education: X Reality*, vol. 2, p. 10011, 2023. https://doi.org/10.1016/j.cexr.2023.100011

[33] G. Barkhuizen, "Number of participant," *Language Teaching Research*, vol. 18, no. 1, pp. 5–7, 2014. https://doi.org/10.1177/13621688135104