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Augmented Reality as a Tool for Improving Conceptual Understanding in Engineering Courses

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ABSTRACT

The development of educational technologies has had a great impact on the sphere of higher education and especially on the sphere of sciences and engineering where abstract ideas and complicated spatial systems may seem difficult to learn. Augmented Reality (AR) has become a new pedagogical experience that can be used to fill in the gap between the theoretical knowledge and their visualization through real-life settings by applying digital content to the natural surroundings. This paper examines how AR has been used to boost the conceptual learning in engineering classes. AR can be used to observe and interact with engineering models through a three-dimensional visualization that facilitates spatial reasoning and cognitive interaction due to its interactive three-dimensional visualization. AR application in the engineering field of study enables experiential learning, motivates learners, and promotes an active involvement of students. Empirical research shows that learning environments based on AR enhance performance on academic, problem-solving, and conceptual levels significantly in comparison to the traditional teaching strategies. Also, AR technologies facilitate group learning and offer feedback in real-time, which enhances knowledge acquisition and understanding of complicated engineering systems. Although it has benefits, there are challenges including technological infrastructure, cost and design of instruction that continue to pose an impediment to its widespread use. However, due to the growing accessibility of mobile AR applications and immersive technologies, potentials are high in the future integration in engineering programs. The study proposes the potential of augmented reality to transform the educational experience in the field of engineering and focuses on its ability to enhance conceptual knowledge, and engagement and learning outcomes in the contemporary classrooms.

Keywords
Augmented Reality, Engineering Education, Conceptual Understanding, Immersive Learning, Interactive Visualization, Educational Technology

INTRODUCTION

The swift change in digital technologies has immensely transformed the learning activities in the institutions of higher learning, especially in science, technology, engineering, and mathematics (STEM) subjects. There are enduring challenges in engineering education whereby the students are unable to comprehend abstract theories, complex systems, multidimensional structures, which are normally not easy to visualize with the conventional teaching methods like lectures, textbooks, and drawings. Since the nature of engineering concepts often rely on spatial reasoning, dynamical processes, and three-dimensional structures, students tend to fail to have an in-depth conceptual knowledge when their learning is confined to a two-dimensional representation. Therefore, teachers and scholars have been discussing new technological solutions that can improve the understanding of concepts and offer more interactive learning opportunities (Ibanez & Delgado-Kloos, 2018; Radianti et al., 2020).

Augmented reality (AR) is one of these new technologies that received significant interest, and it is an effective educational tool that can revolutionize the traditional learning setting. A technology that combines digital content including images, movement, and three-dimensional image models with the physical environment, in real time, to help people act on the physical and virtual environment is called augmented reality. In contrast to virtual reality, which brings an entirely digital world, AR does not replace the real world, but it provides additional virtual objects to be superimposed on the real world using the smartphone, tablet, or wearable display (Azuma, 2010; Bacca et al., 2014). Such a combination of real and virtual worlds gives learners a distinctive chance to study complex phenomena and work with dynamic representations, which cannot be viewed in actual situations or other ways.

Augmented reality has great benefits in engineering education since it allows studying the complex systems of mechanisms, structural designs, and electronic circuits in 3D space. The conventional teaching schemes tend to use stationary illustrations or mathematical formulas which make students build up the spatial illustrations of the engineering structures in their minds. Nevertheless, such representations can be hard to translate into correct mental representations, which can impair the conceptual knowledge and problem-solving skills of students. The AR technologies encounter this issue by providing the learners with engineering models in interactive three-dimensional models whereby the learners can interact, rotate, and view structures in various perspectives. The interactive visualization course facilitates cognitive learning because it helps connect theoretical concepts with practical observation and eventually helps students to gain a better understanding of advanced engineering phenomena (Ibanez et al., 2016; Garzon and Acevedo, 2019).

The introduction of augmented reality in education is more in line with the theory of constructivist learning, which highlights the focus on the fact that knowledge is built through interaction and active involvement in the learning environment. This view says that the learners are better placed to develop further understanding in case they are actively engaged in the exploration of concepts, experimentation with ideas and linking the theoretical knowledge with practical applications. AR-based learning environments can assist in these principles by helping students to engage in direct interaction with virtual engineering models in the real environment. With the help of immersive visualization and hands-on exploration, learners are able to experiment with various configurations, observe cause-and-effect relationships and receive instant feedback on their actions, which will encourage meaningful learning experiences (Bacca et al., 2014; Radianti et al., 2020).

The other notable benefit of augmented reality in engineering education is that it increases the spatial visualization abilities of students; unfortunately, this is essential in comprehending engineering design and structural connections. Lots of engineering studies such as mechanical, civil and electrical engineering demand the student to interpret two-dimensional representations of three-dimensional structures such as blueprints, circuit diagrams and technical drawings. Nevertheless, studies have revealed that, lack of adequate spatial visualization skills is a major cause of misinterpretation of engineering concepts and poor performance by students of engineering. AR technologies allow students to improve their spatial abilities and create a more accurate mental model of engineering systems by using interactive three dimensional models that can be experimented in real-time (Ibanez and Delgado-Kloos, 2018; Garzon, Pavon and Baldiris, 2019).

Besides enhancing the level of conceptual comprehension, augmented reality is also found to enhance student engagement and motivation in engineering courses. The conventional method of teaching engineering uses a lot of lectures and theoretical explanations, and they might decrease the interest of the students and the possibilities of their active participation. Conversely, AR applications provide highly engaging and interactive learning experiences that engages students to actively learn. AR-based learning experiences can arouse curiosity and encourage collaborative problem-solving, as well as increase interest in the engineering subjects due to their novelty and interactivity. It has been shown that students who are exposed to AR-based instructional materials tend to have a greater degree of motivation, satisfaction, and academic success than those, who undergo traditional teaching approaches (Akcayir and Akcayir, 2017; Garzon and Acevedo, 2019).

Moreover, AR can support both experiential learning and inquiry-based learning because it allows students to simulate engineering experiments and create real-time changes in digital models. In engineering classes with laboratory work, AR technologies are able to offer virtual simulations of real-world experiments, which can be tested and students can explore the system behaviors without restrictions of physical equipment or due to safety concerns. These simulations can be useful specifically in engineering fields where laboratory facilities can be costly or unavailable. Using AR simulations with theoretical teaching enables the teacher to design a hybrid learning environment that brings together theoretical knowledge and practical use and improve the learning process in general (Radianti et al., 2020).

The growing access to mobile devices and low-cost AR development platforms has only increased the rate at which augmented reality is used in education. Advanced sensors, cameras and processing functionality in modern smartphones and tablets enable AR applications to be easily implemented in classrooms needing no special hardware. Consequently, AR-based learning tools have found their way to the engineering curriculum of many universities in order to advance the conceptual learning of the students as well as facilitate interactive learning opportunities. According to recent research reports, when AR is used in engineering courses, there are positive results as students have better visualization of 3D problems, understanding of engineering mechanics, and have more engagement in collaborative learning.

The introduction of augmented reality in engineering education is not unchallenged despite the potential benefits that it can bring. The challenges that include technological infrastructure, cost of software development and the requirements of pedagogically sound design of instruction are still major impediments to mass adoption. It is also necessary to train instructors to successfully include AR technologies into the teaching process so that the technology did not become a new toy, playing a destructive role in facilitating the learning goals. Also, to assess the long-term effect of the AR-based learning environments on the conceptual knowledge base and academic performance of students in various engineering subjects, additional empirical studies are required.

However, the research mass suggests that augmented reality has a lot of potential as a new educational technology that can revolutionize engineering education. AR can offer students new possibilities to study complicated engineering concepts by integrating immersive visualization, interactive learning, and real-time feedback, which could not be achieved through the traditional presentation method previously. With the trend toward the digital integration of educational institutions to facilitate the contemporary teaching methods, it can be assumed that augmented reality will be utilized with the increasing significance to the development of conceptual knowledge and learning performance in engineering courses.

LITERATURE REVIEW

The adoption of novel technologies within the field of higher education has become the center of the educational research, especially in science, technology, engineering, and mathematics (STEM) fields. Of these technologies, the use of the augmented reality (AR) has been given more and more attention because of its ability to promote interactive learning and better conceptual comprehension. AR integrates virtual digital content and the real world in which learners are able to visualize complex structures and processes that are hard to understand using conventional teaching strategies. The pedagogical effectiveness of AR in education has been examined over the last ten years, and it is possible to note that it can revolutionize the sphere of engineering education by enhancing visualization, engagement, and conceptual learning results (Azuma, 2010; Bacca et al., 2014).

Engineering education has a tendency of making students learn about complex systems, spatial relationships, and dynamic processes, which cannot always be well illustrated in terms of static diagrams or written descriptions. Conventional teaching methods often use lectures, textbooks and two-dimensional illustrations which might constrain the student to create correct mental images of engineering structures. This has led to poor performance of students in abstract engineering studies, especially those studies which entail spatial thinking and in multiple dimensions. The solution to this challenge is provided by augmented reality, which helps students to engage in learning by operating virtual models with three dimensions and incorporating them into the real world to learn through experience and improve understanding of the concepts (Ibanez & Delgado-Kloos, 2018).

The learning capabilities of AR have been highlighted in a number of studies that show that it can aided in visualization and spatial cognition. It has been an important skill in engineering field especially in such fields like mechanical engineering, civil engineering and architecture where a student is required to read complex structures out of the technical drawings and blueprints. Students who are more spatial in visualizing have been found to do better in engineering studies. AR technologies can help students to explore and manipulate virtual models in the three-dimensional space, a fact that can help them greatly improve spatial reasoning and have a better understanding of engineering concepts (Ibanez et al., 2016; Garzon, Pavon, and Baldiris, 2019). By means of playing with the virtual models, the students will be able to turn, magnify, and observe the structures in various ways and, therefore, build a more in-depth knowledge of the connections between various elements of the engineering systems.

The other significant point that has been brought out in the literature is the use of augmented reality in fostering active and student-centered learning. Constructivist theory of learning infers that learning is acquired by the active interaction and participation of the learning environment by the learner and not by passively receiving information. AR-based learning environments are relevant to this theoretical view by offering immersion learning environments where students can explore and experiment with engineering concepts in hands-on environments. Through the process of engagement with virtual objects, which are situated within real settings, the learners are able to perceive the relation between causes and effects and check their knowledge with the help of the experiential activities. The process promotes a more profound level of thinking and helps to build meaningful knowledge (Bacca et al., 2014; Radianti et al., 2020).

It has also been found out that AR applications can make student more inclusive and motivated in courses related to engineering. The standard methods of teaching that involve lectures, do not always attract the attention of students and promote their active learning, especially when it comes to highly technical or abstract material. On the contrary, AR technologies also bring some elements of interactivity and visualization, which can make learning processes more interesting and pleasant. Research has reported that students taught using AR-based learning platforms tend to record improved rates of interest, motivation, and satisfaction in relation to students taught using traditional ways of instruction (Akcayir and Akcayir, 2017). Interactive AR stimulates students to engage in the learning process and this can enhance their learning overall and understanding of concepts.

The other area of study that has been examined in the literature is the application of AR in collaborative learning in engineering education. Engineering projects are typically done in groups and teams, thus it is also significant that students should learn to communicate and solve problems within groups. AR can be used in collaborative learning whereby more than two users can interact with the same virtual model at a particular time. Students can work together to design solutions to engineering problems through shared visualization environments where all students can discuss design options together and analyze engineering problems. This team learning strategy does not only increase the level of conceptual learning but also enables students to acquire valuable critical professional skills essential in the practice of engineering (Garzon and Acevedo, 2019).

Empirical studies have also been done to determine the effectiveness of AR in enhancing conceptual understanding in various educational settings. Indicatively, Ibanez et al. (2016) examined how AR based learning tools could be applied in engineering courses and discovered that their interviewees who used AR applications showed a much higher conceptual understanding relative to students who used conventional instructional resources. Equally, Garzon and Acevedo (2019) meta-analysed the AR-based educational interventions and arrived at the conclusion that augmented reality positively affects the learning process, especially in the classes where visualisation and spatial thinking skills are necessary. Such results indicate that AR is a viable teaching aid that can be used to improve engineering studies.

The other sphere of research is the presence of AR technologies and mobile learning platforms. The popularity of smartphones and tablets has exposed students and educators to AR applications. Mobile AR will enable learners to have access to interactive learning resources at any time and place thus learning is not restricted to a formal classroom setting. Radianti et al. (2020) state that mobile AR applications could complement the flexible and personalized learning experience and allow students to learn about engineering concepts at their own pace. This flexibility comes in handy especially in learning institutions where students tend to have different learning preferences and schedules.

Besides making the visualization and interaction more effective, AR technologies have been demonstrated to contribute to better knowledge retention and skills of problem-solving. AR simulations with interactive mode enable the students to study how engineering systems behave in various circumstances and this makes them learn the principle on which the engineering systems operate. The opportunity to work with virtual models and watch the results in real time allows the students to gain a better perception of the engineering concepts and implement the obtained knowledge into the real-life problem-solving activities. Studies have shown that AR based learning systems have the potential to enhance the skills of students to analyze complex engineering problems and come up with pertinent solutions (Garzon, Pavon, and Baldiris, 2019).

Although AR has many benefits in the education of engineers, there are several issues, which restrict its use among the teachers. The technological infrastructure needed to facilitate the AR-based learning environments is among the major challenges. In spite of the fact that mobile devices have brought AR closer to users, high-quality AR applications can be developed and implemented with high technical skills and financial costs. Institutions of higher learning can also encounter issues of incompatibility with software, hardware constraints, and adopting AR technologies in the current learning management system (Radianti et al., 2020).

The requirement to design the instruction efficiently, as well as the implementation of AR technologies in educational institutions, is another problem that was found in the literature. The mere introduction of AR tools in the classroom will not necessarily result in better learning. Rather, AR applications need to be thoroughly constructed in ways that correspond to the learning goals and pedagogical practices. Teachers should also make sure that AR activities enhance valuable learning processes, not only as technological additions with no educational purpose. An efficient instructional design means combining AR simulation with learning content, giving effective instructions to students, and assessing how AR-based interventions affect the learning results (Akcayir and Akcayir, 2017).

Moreover, AR integration in engineering education should be successful and this would be possible with proper instructor training and support. A lot of teachers might not be technologically proficient to create or execute AR-based learning tasks. Training workshops and professional development programs are thus needed to enable the instructors to take note of how AR technologies can be applied effectively in their teaching programs. Instructors might also be reluctant to use AR technologies without this proper training, which can restrict the value of these technologies in learning institutions (Ibanez and Delgado-Kloos, 2018).

Other more recent studies have also examined the opportunities of augmented reality to be integrated with other more still developing technologies like artificial intelligence, virtual laboratories, and immersive learning environments. These combined technologies may also be used to increase the educational value of AR by offering adaptive learning opportunities, customized feedback, and more advanced simulations of engineering systems. As an illustration, AI-based AR applications may review how the students interact with virtual models and give them real-time feedback to help them navigate through the process of learning. These innovations are good prospects of future research and development in the field of engineering education (Radianti et al., 2020).

On balance, the available literature shows that augmented reality has much potential as a means of teaching and learning concepts in engineering classes. AR technologies can be new to help change the traditional engineering education, as they offer interactive three-dimensional visualizations, facilitate the application of experiential learning, and increase the engagement of students. Even though the issues of technological infrastructure, instructional design, and instructor preparation still exist, the constant development of AR technology and mobile computing is expected to enable broader use in the future. Since the research on educational potential of AR is still ongoing, it is believed that augmented reality will become an even more significant element in developing innovative learning settings, which will allow the achievement of deeper conceptual learning in engineering educations.

METHODOLOGY

Research Design

The current study is based on quantitative research methodology in order to determine the effectiveness of augmented reality (AR) as an aid in enhancing conceptual learning in engineering courses. Quantitative research is very popular in the field of education technology research since the researcher is able to assess the learning outcomes, interest and understanding of concepts involving the statistical methods (Creswell and Creswell, 2018). The research study employed in the study is descriptive and correlational. Descriptive research can be used to determine the perception and experience of students considering the use of AR in learning contexts, whereas the correlational analysis helps to evaluate the correlation between the AR-based instructional strategies and the conceptual knowledge of students. The design will allow the researcher to conduct an analysis of the effects of AR technology on the learning outcomes of the students in a systematic manner.

Population of the Study

The study population comprises of undergraduate learners pursuing engineering courses in institutions of higher learning. Engineering education tends to encompass complicated theoretical ideas, spatial visualization, technological problem resolution, and so, as a discipline, it is appropriate to study the efficiency of the augmented reality technologies. Students who are enrolled in courses like engineering mechanics, structural analysis, electrical circuits, and mechanical design were regarded as a part of the population as most of them normally demand excellent conceptual knowledge and visualization skills.

Sample and Sampling Technique

A random sampling method was used to select a sample of 250 engineering students out of the target population. Random sampling helps to remove bias in sampling since all the members of the population can get an equal chance to be selected and it enhances the credibility of the study results (Etikan & Bala, 2017). The chosen participants were separated into two groups, namely, the experimental group and the control group. The selected concepts of engineering were taught to the experimental group with the help of augmented reality applications, whereas the control group was instructed with the help of the traditional lectures with the aid of textbooks and stationary diagrams. This comparison allowed the researchers to compare the effectiveness of AR-based learning to enhance conceptual understanding of students.

Data Collection Instruments

Two major tools were used to gather data; a structured questionnaire and a conceptual assessment test. The questionnaire was structured to determine the perceptions, level of engagement and learning experiences of the students concerning the application of augmented reality in teaching of engineering subjects. The questionnaire was also composed of some items that were constructed using a five-point Likert scale, which was strongly disagree (1) to strongly agree (5). Likert scale tools are a popular tool in educational research since it enables the researcher to measure the attitude and the perceptions of the student in a way that is systematic (Field, 2018).

The conceptual assessment test was designed to measure the knowledge of students with regard to engineering concepts that were taught in the instructional period. The test was made of multiple-choice questions and short problem-solving tasks that were connected with course material. They were done to both the experimental and control group to compare their levels of conceptual understanding at the end of the instructional intervention.

Reliability and Validity of the Instrument

Cronbach alpha was employed in order to determine the compatibility between the items in order to guarantee reliability of the questionnaire. Cronbach alpha is a common statistical test used to assess the reliability of survey tools in the social science and research in education. When the value of Cronbachs alpha exceeds 0.70, it is regarded as acceptable to make reliable measurements (Hair et al., 2019). The reliability coefficient of the questionnaire derived in this study was higher than the acceptable level which meant that the instrument was reliable in measuring the perceptions and learning experience of the students with regard to being instructed through AR-based instruction.

Experts were used to determine content validity. A number of subject experts in engineering education and educational technology reviewed the questionnaire and items of assessment to make sure that they captured the constructs under measurement well. Their comments were used to revise the phrasing and format of the items to make them more concise and specific.

Data Collection Procedure

Data collection was done in several steps. First, the participants could be informed of the aim of the research and desired their consent to participate in the study. Mobile AR applications and interactive 3D models on engineering concepts were used to introduce the AR-based learning activities to the experimental group. These applications gave the students an opportunity to visualise and manipulate engineering structures in real time. In the meantime, the control group was taught by traditional pedagogical techniques, e.g. lectures, textbooks, and fixed diagrams.

The teaching intervention was a few weeks long so that the students could have enough exposure to the AR-based learning environment. The conceptual assessment test and the questionnaire were given to both groups after the end of the instructional period to assess their conceptual knowledge and learning experiences.

Data Analysis Techniques

The statistical analysis was performed on the data gathered by the researchers in order to determine the effects of augmented reality on the conceptual knowledge of students. To summarize the demographic features of the participants and their answers to the questions in the questionnaire, first, the statistics of descriptive character (mean, standard deviation, and frequency distributions) were employed to describe the data. The descriptive analysis assists in presenting a report on the perception and experience of the student on the use of AR in engineering education.

Second, correlation analysis was undertaken to identify the correlation between the use of augmented reality and conceptual understanding of the students. Correlation analysis is useful in establishing the nature and the direction of relationship between variables.

Third, the reliability analysis of Cronbach alpha was adopted to check the internal consistency of the questionnaire items. Last but not the least, structural equation modeling (SEM) was used to test the causal association among the use of augmented reality, student engagement, and conceptual understanding. SEM is popular in the field of educational research since it enables a researcher to examine sophisticated associations between numerous variables at the same time (Hair et al., 2019).

These statistical methods give a detailed analysis of the effect of augmented reality on conceptual learning outcomes in engineering learning.

RESULTS AND DATA ANALYSIS

Demographic Respondent Characteristics.

The demographic analysis gives a summary of participants who will be involved in the study. There were 250 undergraduate students of engineering who were involved in the research. The demographic variables were gender, academic year and academic engineering discipline. The realization of these features can be used to interpret the study findings and to understand whether the sample sizes reflect the target population in a proper way.

Table 1: Demographic Profile of Respondents

Variable	Category	Frequency	Percentage
Gender	Male	160	64%
	Female	90	36%
Academic Year	2nd Year	80	32%
	3rd Year	95	38%
	4th Year	75	30%
Engineering Discipline	Mechanical	85	34%
	Civil	70	28%
	Electrical	55	22%
	Other	40	16%

The demographic analysis shows that most respondents were male students and it is normal because such is the common gender balance in most engineering courses. The majority of the respondents were in their third year of their engineering courses implying that they had already acquired the basic knowledge on their respective subjects. The largest percentage of the sample was students of mechanical engineering, which was followed by civil and electrical engineering students.

Descriptive Analysis
The descriptive statistics were performed to determine how the students perceive the application of augmented reality (AR) in engineering education. Variables that were analyzed included AR usability, learning engagement, visualization improvement, and conceptual understanding.
Table 2: Descriptive of the Study Variables.

Variable	Mean	Standard Deviation
AR Usability	4.12	0.63
Learning Engagement	4.05	0.71
Visualization Improvement	4.21	0.58
Conceptual Understanding	4.18	0.65

According to the descriptive statistics, students tended to report the positive perceptions of augmented reality as a learning tool in general. The best mean score was realized in relation to the improvement of visualization (Mean = 4.21), which revealed that AR played an important role in improving the ability of students to visualize the engineering structures and processes. The mean score of conceptual understanding was also high (4.18), which implied that learning based on AR added effect to the understanding of engineering concepts in students.
The mean learning engagement score was determined as 4.05, which meant that AR-based instructional technique was more engaging and interactive to students compared to the conventional teaching approach. On the same note, the AR usability was rated highly in the mean, and that indicates that the students viewed the technology as friendly and convenient in the learning process.
Reliability Analysis (Cronbach's Alpha)
In order to get the reliability of the measurement instrument, the alpha of Cronbach was computed to ascertain the internal consistency of the questionnaire items.
Table 3: Reliability Statistics.

Variable	Cronbach's Alpha
AR Usability	0.82
Learning Engagement	0.85
Visualization Improvement	0.87
Conceptual Understanding	0.84

The reliability findings show that all the constructs had a Cronbach alpha value stronger than the recommended alpha of 0.70, which proves that the scales used in the research to measure them are reliable (Hair et al., 2019). Visualization improvement was the most reliable (0.87) implying that there is strong internal consistency in the items to measure the construct.
Correlation Analysis
The correlation analysis was conducted to check the relationships between the use of augmented reality and the study variables. The findings are used to establish whether AR is associated with better conceptual understanding in engineering classes.
Table 4: Correlation Matrix

Variable	AR Usability	Learning Engagement	Visualization	Conceptual Understanding
AR Usability	1			
Learning Engagement	0.61**	1		
Visualization	0.67**	0.63**	1	
Conceptual Understanding	0.65**	0.68**	0.72**	1

(**p < 0.01)
The correlation analysis indicates that the variables have strong positive relationships. AR usability demonstrates a big positive relationship with learning engagement (r = 0.61) and conceptual understanding (r = 0.65). The visualization enhancement has the highest connection with conceptual understanding (r = 0.72), which implies that the ability to improve the visualization offered by AR can play an important role in helping students to learn the concepts.
These results indicate that augmented reality is important in enhancing the comprehension of engineering students towards complex concepts through visual representation.
The Structural Equation Modeling (SEM) Analysis
The effects of the application of augmented reality (AR) on learning through visualization and conceptual learning were investigated with the help of structural equation modeling (SEM). SEM enables the researcher to test intricate associations among two or more variables at once.
There are three main paths analyzed by the SEM model:

- AR Usability - Learning Engagement.

- AR Usability - Image Enhancement.
- Visualization Enhancement - Conceptual Insight.

As it was analyzed, AR usability affects the engagement in learning and the improvement of visualization significantly. The enhancement of visualization, in its turn, influences conceptual understanding in a positive way to a great extent. Such results suggest that augmented reality can be used to improve the level of understanding by students mainly because it will help them to visualize engineering structures and processes.

The findings of the SEM also indicate that the engagement in learning is a mediating aspect between the use of AR and conceptual learning. Learners that use AR-based learning tools actively have higher chances to acquire deeper conceptual understanding in engineering subjects.

DISCUSSION

The results of this paper are a good indication that the concept of augmented reality (AR) can be used to have a significant impact on the conceptual understanding of the learners studying engineering programs. The outcomes of the descriptive analysis showed that students believed AR to be an efficient educational tool, which enhances visualization, engagement, and understanding of complicated engineering concepts. Engineering disciplines tend to incorporate multidimensional designs, machine operations and abstract procedures that are not easily deciphered in traditional teaching approaches like the lecture and the fixed diagrams. The capability that augmented reality offers of displaying three-dimensional interactive models enables the students to view the engineering structures in real-time and real-world perspectives and dimensions, which offers an opportunity to engage in more cognitive thinking and conceptualization. These results are consistent with the previous studies which claimed that AR-based learning spaces facilitate experiential learning and assist students in building correct mental images of complex systems (Ibanez & Delgado-Kloos, 2018).

The correlation analysis also evidences the usefulness of augmented reality in engineering education because it shows that there are strong positive interrelations between AR usability, learning engagement, visualization improvement, and comprehension of concepts. Improvement in visualization was associated with conceptual understanding the most, which implies that the most beneficial aspect of AR is that it can lead to better spatial visualization. The interpolation of two-dimensional representation of three-dimensional structures is a common issue with engineering students as it may cause misunderstanding and problems in applying the theoretical knowledge. As AR technologies allow learners to manipulate virtual objects and observe the working of the system in real-life, they assist in addressing the divide in the theoretical explanations and practical visualization. This observation is aligned with the previous research that revealed that AR enhances spatial cognition and problem-solving abilities in STEM learning (Garzon & Acevedo, 2019).

The results of the structural equation modeling also suggest that the role of student engagement is rather significant in the correlation between augmented reality and conceptual understanding. As students engage with the AR based learning tools, the students are more actively engaged in the learning process, which facilitates curiosity, exploration and critical thinking. As opposed to the conventional lecture-based learning processes, AR-based learning systems prompt students to engage in hands-on practice, which helps observe, experiment, and analyze engineering models. The given interactive learning method is consistent with the constructivist learning theory that puts strong emphasis on the role of active involvement in knowledge construction (Bacca et al., 2014). With these interactive experiences, the students can relate the theoretical knowledge to the practical application, thus understanding the knowledge better and retaining it.

The other potential implication of the research is that the augmented reality has the potential to change traditional engineering classrooms to be more student-centered and immersive learning environments. The combination of AR technologies enables the teacher to introduce the engineering concepts in new forms that will encourage a deeper comprehension and teamwork learning. AR simulations help students to analyse virtual models, discuss engineering designs, and solve complex problems together. These team building exercises not only increase the level of conceptual knowledge but they also equip the students with communication and teamwork skills that are critical in professional engineering practice.

Although these positive results were achieved, such a study also shows that there are a few problems related to the application of augmented reality in higher education. Implementation of AR technologies needs proper technological systems, such as compatible equipment, stable software platforms, and technical assistance. Institutions of higher learning might have financial limitations and logistical problems in the process of implementing AR-based learning into the current curriculum. Moreover, the instructors need to be trained in order to plan and execute AR-based instructional tasks. Unless the educational advantages of AR are well planned through proper instructional design, they might not be adequately achieved. Consequently, universities should invest in faculty development and technology to make sure the integration of AR technologies into engineering education is successful.

All in all, the findings of this research prove that the augmented reality has significant potential in terms of enhancing the conceptual knowledge in engineering classes through a better visualization, improved student engagement and diversified learning experience. The use of AR-based methods of instruction is also expected to grow in importance in contemporary engineering learning as digital technologies keep gaining more and more significance.

CONCLUSION

This paper has analyzed how augmented reality can be used as a teaching aid in enhancing the conceptual learning of engineering subjects. The results indicate that the use of AR-based learning environments can contribute greatly to the capability of students to perceive the complex technological concepts in the engineering meaning and to actively participate in the process of knowledge acquisition. The statistical test indicated that there are strong positive correlations between the use of augmented reality, engagement in learning, visualization enhancement, and conceptual understanding. The findings indicate that AR technologies can be useful to counter the gap between theoretical and visualization approaches so that students can gain a deeper understanding of engineering principles. Augmented reality offers the chance to provide students with a more meaningful, immersive way of studying engineering systems through the use of interactive three-dimensional models within the learning space. The paper thus concludes that augmented reality is an effective educational technology that can change the way engineering is taught traditionally and enhance learning in institutions of higher learning.

RECOMMENDATIONS

Resting on the results of this paper, it is possible to offer a number of recommendations which would contribute to the improvement of the application of augmented reality in engineering education. To begin with, colleges and universities ought to think about the possibility of incorporating AR technology into their engineering programs to facilitate the interactive and experience-oriented learning process. Second, the universities ought to invest in technological infrastructure and make mobile AR applications available to students so that they can visualize complex engineering structures. Third, professional development activities are to be arranged so that the instructors would be trained on how to effectively use the AR-based teaching approaches and instructional design. Fourth, academic performance and skill development of students in various engineering disciplines in the long-term effects of augmented reality should be examined in the future study. Last but not least, researchers are to examine how augmented reality can be integrated with other emerging technologies like artificial intelligence and virtual laboratories so that they could develop more sophisticated and flexible learning opportunities in engineering education.

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