Teaching Design Project in Introductory Engineering Course Using 3D Modeling and Immersive Virtual Reality

Osama Halabi[1(✉)], M. Samir Abou El-Seoud[2], and Vladimir Geroimenko[2]

[1] Qatar University, Doha, Qatar
ohalabi@qu.edu.qa
[2] The British University in Egypt, Cairo, Egypt
{samir.elseoud,vladimir.geroimenko}@bue.edu.eg

Abstract. This paper presents a new approach for delivering the project component in introductory engineering course. The approach is based on using 3D modeling software to create the prototype of the product. Furthermore, immersive VR display were utilized to enable the students to explore and inspect their design in different stages and discover the problems in the design. The approach enabled the students to get perception of their design and interact with the model from different angle and navigate around which gave them closer look at the design that usually impossible using the traditional 2D display. The results showed that the VR approach increased the attainment of the students in the project.

Keywords: Project-based learning · Immersive education · Virtual reality

1 Introduction

Preparing students to cope with emerging and futuristic technological innovations learners need to be taught using well engineered interactive training environments and methods [1] that deliver results close to hands on training, from the first moment they admit into the university. The bright potential of tomorrow is linked to application of engineering and IT concepts [2]. Virtual Reality (VR) provides real time visualization and interaction within a virtual world that closely resembles a real world [3, 4]. Moreover, with the recent advancement in virtual reality technology VR systems became affordable and relatively cheap with new consumer devices and game consoles adopted at homes is to be considered a new shift in the gaming industry. VR is able to provide a constructivist learning because it enables the learners to be actively involved in highly interactive environment [5]. Constructivist learning model, which was first proposed by Reigeluth [6], is a philosophy of learning that believes knowledge is constructed by learner through experience and activity [6, 7]. Many studies pointed out how VR technology that equipped with various technical capabilities can support constructivist learning principles [8, 9].

The main learning objective of providing design project in first year engineering fundamentals course is to enable the students to apply and practice the engineering design process that has been covered in theory, in addition to teach the student to think

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and consider practical issues and constrains while creating solution for any project. The traditional project style in helping students to achieve these objectives suffers from many problems. The project is either too ambitious therefore the students are not able to actually implements or test their assumptions or it is very simple where they can apply only some design and engineering concepts that still close to K-12 level, as a result the students will not be able to apply all the design steps. The proposed idea in this paper is providing a new learning style to enable the students to design, create, and evaluate their prototypes with the help of virtual reality technology. The design and development of the product is achieved using 3D modeling tools (virtual prototyping). Moreover, virtual reality immersive CAVE display were utilized to enable the students to check and evaluate their design in interactive and intuitive environment with high sense of presence, realism, and immersiveness. Using this new approach is expected to increase the students' motivation and their attainment in project completion.

Interactive virtual environment and simulation is a mythology for teaching that allow learners to practice and test their knowledge in circumstances that are similar to real world. In the proposed approach the students designed and created the virtual world themselves. This expected to increase the information retention and add new dimensions to the learning process such as creativity and motivation.

The research in [10] demonstrated the feasibility of applying VR as a tool for conveying engineering concepts to first year engineering students. They concluded that the teaching tool contribute largely to the student retention of engineering concepts although no results were published. They also used a non-immersive VR 3D design platform as a teaching tool. In this research we use a fully immersive virtual environment with large scale display that provides high sense of presence and interactivity. Lee et al. and her colleagues [11] studied the potential of desktop VR technology to support and enhance learning and developed a theoretical model and a board framework to explore the determinants of learning effectiveness in a desktop VR-based environment. The result show that satisfaction and perceived learning effectiveness influenced greatly the learning outcome. Meanwhile performance was less influenced due to the fact that performance achievements is influenced by a myriad of other factors. Considering the previous result, the proposed system is expected to score high in the measurement criteria that related to presence, motivation, control and active learning, and reflective thinking which will lead to higher influence on the learning outcomes. The work in [12] presented teaching methodology for a practical course in virtual reality for engineering students. No solid evaluation of the impact of using VR on the overall performance or outcome was presented, however it was noted that the students' motivation increased.

The paper presents a new approach for conducting engineering design project using 3D modeling as a prototyping technique and immersive Virtual Reality (VR) platform to inspect the prototype and evaluate the design. It also presents an assessment of the effectiveness of this approach on the performance of the students who are taught using this teaching approach compared with traditional approach.

2 Infrastructure

The course project demonstration was hosted in the Virtual Reality Lab in the College of Engineering at Qatar University. The Lab was established in 2015 with the state-of-art equipment in virtual reality hardware and software. The lab is equipped with high fidelity virtual reality environment and a distributed stereoscopic visualization in a four-sided C.A.V.E. (Cave Automatic Virtual Environment) display (3walls + floor). The display is supported with high-precision tracking using PPT (Precision Position Tracking) with high speed optical sensors. This enables interaction ability using tracked wands. The whole system provides large-scale screens with stereoscopic vision and high degree of interactivity, see Fig. 1.

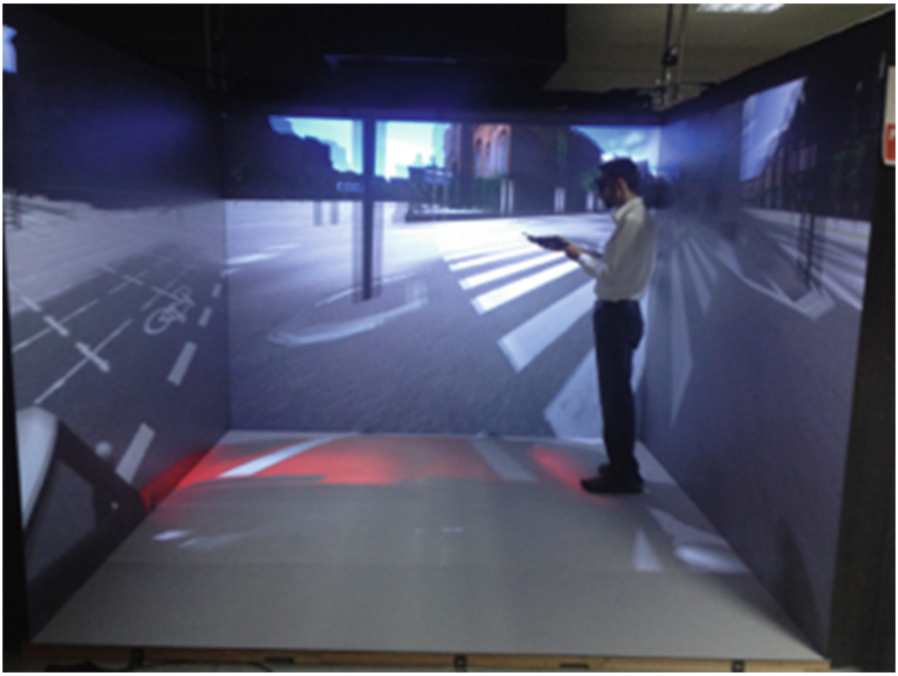


Fig. 1. CAVE system at Qatar University

3 Methodology

The approach is based on comparison between the traditional approach of delivering design project and the new proposed VR-based approach in terms of performance. The two approaches were applied on different sections during different semesters. The traditional approach is based on giving the students several project ideas and ask them to select and develop final prototype. Since the main objective of the design project is to enable the student to apply all the engineering design steps from idea generation to testing and evaluation, the ideas had to be simple and selected carefully to be applicable and easy to implement so that the student would be able to create the final prototype and test it. This obviously limited the scope and level of difficulty of the projects and also constrained the creativity of the students to generate different approaches and ideas to address the objectives of the project.

In the VR-based approach the students were given a real-life project idea. They were asked to apply all the engineering design steps, therefore, each team have to create three designs and select the best design based on the evaluation matrix. After selecting the best design, they have to create a prototype. Creating sophisticated and detailed prototype is difficult to achieve using the traditional tools. In the proposed approach we utilized the 3D modelling technique which is widely used in many industries to save time and money during the design stage. Therefore, the student was asked to use 3D modelling software to develop their prototypes and encouraged to add all the fine details that usually needed in real-life solution. In our case, they were taught how to use SketchUp Software which was easy and sufficient to create detailed design. Figure 2 shows how details were added, e.g. assistance handles were added in specific spots, Fire extinguisher, sockets and coffee maker. Figure 5 as well shows how students cared about all the details that usually exist in real-life kitchen.

Fig. 2. The designs considered all the necessary details to produce final real model. For example, the handle to assist the person in wheelchair, the fire extinguisher for safety, the sockets, coffee maker, and other details.

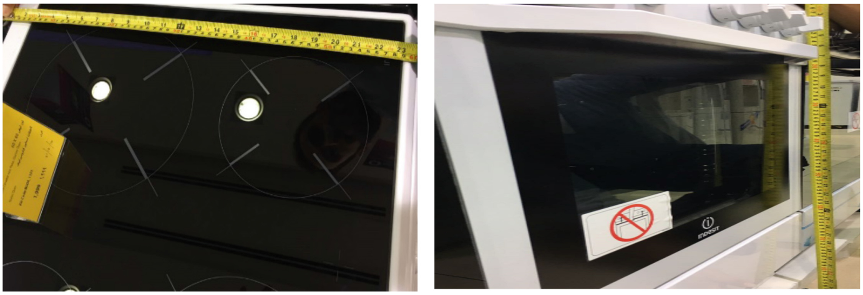
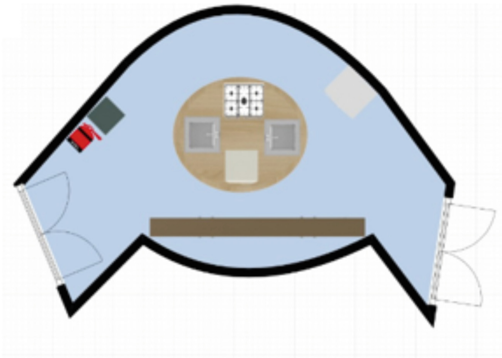


Fig. 3. Students went to the market to get real price and dimensions of the components. The left photo shows electrical stove, and the right photo is a microwave.

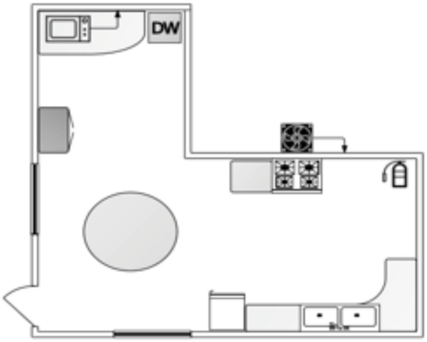
The students had to deliver the 3D model in a certain format to be able to view it on CAVE display. This was simple enough as the software provides the capabilities to export to different 3D formats. Also, they were taught how to align the model view to the CAVE display so that the viewer stands in the middle of the design. The students enjoyed many small details on how to deal with 3D graphics and were impressed to see their work on the display and all achieved by themselves. The students were first asked to brainstorm to find at least three different solutions and then start analyzing each solution based on the criterial of success and constrains that the students identified. Figure 4 shows three different solutions presented from which the circular design was selected based on the evaluation matrix for the three kitchen designs.

After selecting the final design, the students started developing their prototype using 3D modeling software. To allow students to check their design and get feedback and not leave it to the last day of final submission, two visits to Virtual Reality Lab were arranged for the students, one to check their initial design and another one to present their final design. In the first visit, each group were able to test their design, navigate, and interact with it. Furthermore, the demonstration was in front of all class which also provided good chance for other students to see different ideas and also to give their comments and feedback. The whole experience was engaging to other student as they were also able to wear 3D glasses and experience with the presenter the design. This increased the involvement of the whole class and provided a great atmosphere for constructive discussion and comments. The CAVE display provided immersive experience with almost real scale size so the students were able to inspect their design and were able to find many problems that usually hard to detect in 2D display. This step was very essential and very useful for the students and enabled them to apply evaluation and enhancement steps on their design. The students addressed these problems in their second visit where they demonstrated the final design. Figure 5 shows the final design for the design kitchen in Fig. 4(a).

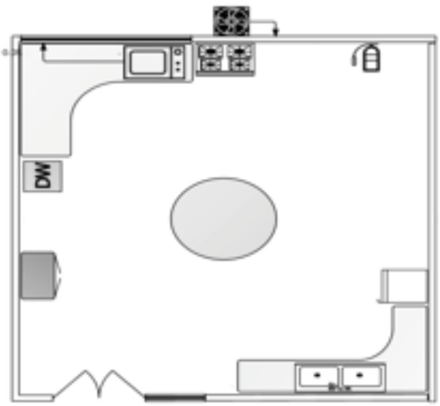
One additional important details considered in the design of every project is that the students were asked to use real scaling in their design as this will be reflected in the CAVE display. This forced them to use real dimensions for every object used in the design. To achieve this objective, they had to look in the market for real components and get their dimensions to be able to add them to their design. Figure 3 shows how



(a) The Circular design of the kitchen.

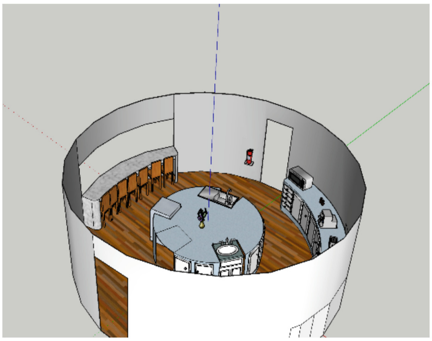


(b) The L-shape design of the kitchen.

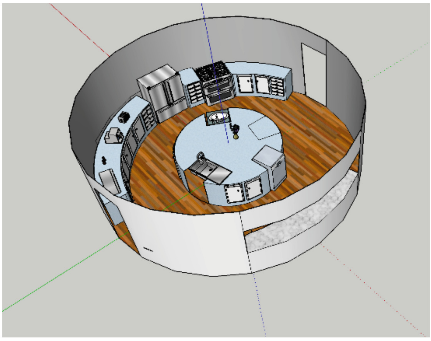


(c) The square design of the kitchen

Fig. 4. Three designs represent three different creative design ideas for the kitchen as presented on the final report as an example for one team project.



(a) Front top view of the kitchen.



(b) Back and top view of the kitchen

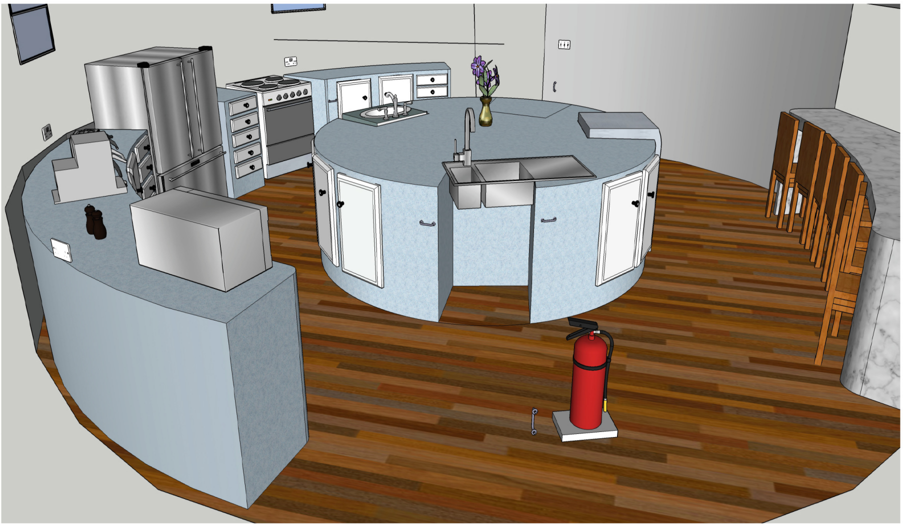


Fig. 5. The 3D model of the kitchen with all the details. The model is an implementation of the design presented in Fig. 2(a).

students went to the market and selected the components for their price to meet the budget constraint and also measured them before adding to the design.

4 Experiments and Result

The students were asked to design a kitchen for wheelchair people with specific constraints on budget, room size, and materials. Safety aspect was crucial for the success of the project in addition mass production. The number of students for the traditional section were 24 students, and they were 31 students in the section that VR approach was applied. Questionnaire was used to explore factors about the project difficulty and how it motivates the student to work as a team. As a quantitative measure, the grade of the students at each section was used to compare between the two approaches. We used the project grade to evaluate the effect of each approach on the student performance in conducting their project specifically.

Two sessions were arranged for the students to visit the lab and check their design in the CAVE display. In the first visit they were asked to inspect their model and identify the problems by imagine themselves using the kitchen. The interactive high fidelity display enabled the students to discover many problems in the design that was impossible to see in normal desktop display as expressed by the students. Issues like the positions of the electrical sockets, the difficulty in reaching out the end of the stove, the lack of safety, difficulty in cleaning in between the cabinets, etc. The instructor was also able to give a useful feedback about the design and gives hints about how to improve the design. The students were asked to consider these issues and think how to modify their design to address them. This considered as first evaluation of the product and enabled the students to experiment the nature of iterative design process. They were given a second chance to demonstrate how they addressed the design problems that discovered during the first visit and how they improved the final design as well. The final design during the second demonstration in virtual reality lab of the same kitchen presented in Fig. 5 can be seen in Fig. 6.

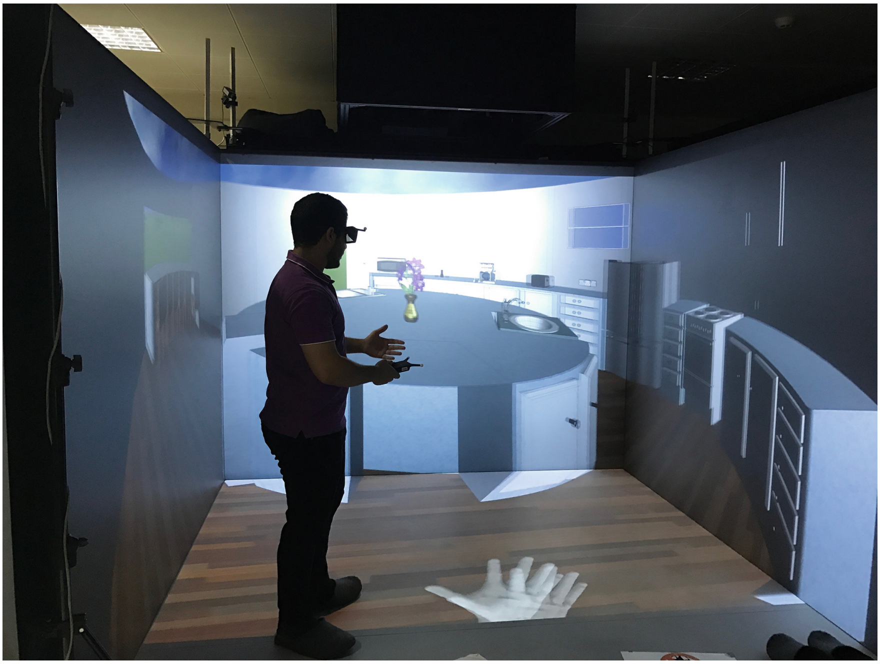


Fig. 6. The student is demonstrating the final design of the kitchen in CAVE. The design is the final design for the same kitchen presented in Fig. 4.

The analyses of the project grade for the two sections showed that the average final grade value was 84.54 for the students used the VR approach compared to 77.04 for the students who used the traditional approach as can be seen in Fig. 7.

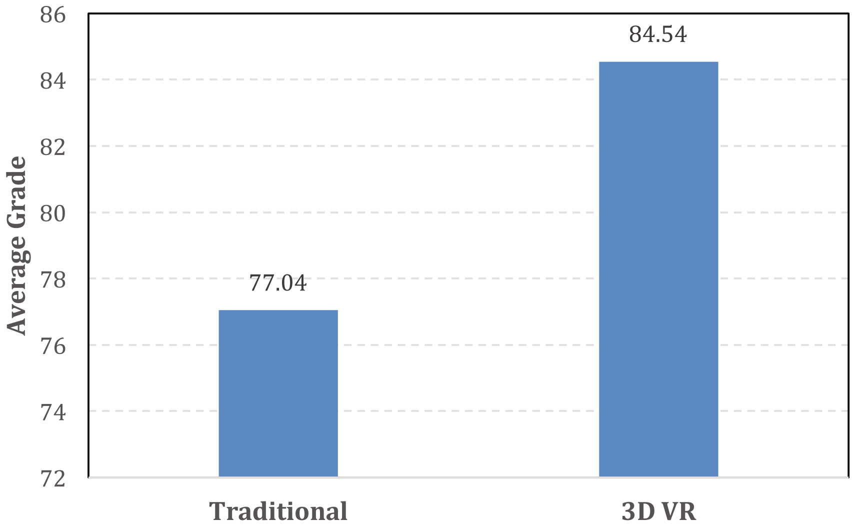


Fig. 7. The final grade for project grade for VR approach and traditional approach.

Further analysis to the final prototypes showed that the students were able to add fine details on the design and addressed all the safety and accessibility issues as adding these details is much easier than real mockups or any other tools for prototyping. Another result that can be concluded from the questionnaire is that the students were very excited about using this approach and many thought that this considered an important skill for their carrier as engineers and would be very useful in the future. This also might be the explanation on why they were also very motivated as well.

5 Conclusion

This research explored the delivery of introductory engineering course to teach engineering design process and skills using a project-based learning methodology to implement a virtual prototype in fully immersive VR environment. An assessment of the approach is provided based on the student performance. The use of 3D software and VR as a new teaching-learning environment can empower the engineering students with new tools to design, create, and evaluate new ideas. The new advancement in VR technology increased the quality of visualization and make it affordable. This makes VR a viable alternative to traditional teaching method. Furthermore, VR can be a powerful tool for testing and evaluating new products and ideas. The result of this research also demonstrated how the students effectively interacted with environment and were able to visualize their design problems. Hence, it is important to emphasize that VR is not merely for visualization purposes, instead it offers an improved method of interaction and visualization that can be applied in real engineering problems. This can be applied to different engineering disciplines including mechanical, electrical, chemical, and architectural.

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