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Effectiveness of Immersive Virtual Reality for Mechanical Engineering Capstone Courses

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Abstract: This paper, a continuation paper to the work presented at a previous ASEE conference as a "Pilot" planned research [1], discusses the research results of integrating virtual reality (VR) in a Mechanical Engineering Senior Capstone Course. The paper discusses the layout of the VR lab, its CAD software and hardware integration components that facilitated the immersive experience of virtual prototyping, and the effectiveness of utilizing virtual prototyping as a substitute for rapid prototyping during early stages of engineering design. The paper also provides benefits and challenges of using VR technology and recommendations for its successful implementation in a capstone engineering design class.
Keywords: Virtual reality, Additive manufacturing, 3D printing, Engineering design, Simulation

I. INTRODUCTION

This paper, a continuation paper to the work presented at a previous ASEE conference as a "Pilot" planned research [1], discusses the research results of integrating virtual reality (VR) in a Mechanical Engineering Senior Capstone Course. The paper discusses the layout of the VR lab, its CAD software and hardware integration components that facilitated the immersive experience of virtual prototyping, and the effectiveness of utilizing virtual prototyping as a substitute for rapid prototyping during early stages of engineering design. Additionally, benefits and challenges of using VR technology and recommendations for its successful implementation in a capstone engineering design class will be presented.

The use of virtual reality (VR) in engineering education is expanding due to the widespread utilization of VR in industry. There is evidence that constituents of engineering programs across the globe are demanding VR literacy in engineering curriculum. VR has been extensively used in product development visualization as a fast substitute to rapid prototyping [2]. More emphasis has been observed in the past 20 years in utilizing VR in product marketing and voice of customer surveying.

The utilization of VR spans over a wide spectrum of sophistication. From head-mounted low-cost VR systems to more upscale head mounted displays with advanced on-board computing and wider field of view, to passive rear projection VR walls, to active VR rear projection walls and enclosures. The VR labs utilized in academic and industrial settings are also varying in user experience sophistications. From completely non-tracked user VR to fully optically tracked immersive VR experience. In the early 2000's, basic graphic curriculum was reported to be using VR as reported in [3]

Schools of engineering around the globe are integrating VR into curriculum enhancement and delivery methods. For example, architectural engineering design education has shown a dramatic shift in utilizing VR. Due to the abundance of massive architectural CAD content, VR simulations of architectural content has proliferated into design studios and architectural design schools [4]. Other disciplines of engineering, such as chemical engineering, are catching up and showing promising practical benefits of utilizing VR in education as reported in [5].

VR is also seeing increased utilization in the field of consumer products development, voice of the customer and consumer usage, and experience data collection [6]. As it has been a very feasible simulation platform for aviation applications, VR has also penetrated the flight simulation and training market [7]. Consumer behavior and perception of digital consumer products was also benefiting for from VR technology [8]. VR has gone as far as probing virtual store emotional state and store attractiveness as recently reported in [9].

The most challenging aspects of adopting VR in industry and in engineering design education, is the fidelity (visual quality) of the VR content as displayed in VR environment. The higher the fidelity, the higher the end-user satisfaction and viability of VR as a design review and visualization tool [10]. In the following parts of this paper, the adoption of active and immersive VR system in an engineering design capstone class will be presented.

II. BACKGROUND ON MECHANICAL ENGINEERING CAPSTONE

The undergraduate Mechanical Engineering program is one of several newly introduced engineering programs in the GameAbove College of Engineering and Technology at Eastern Michigan University (EMU). The College has five major priorities including increasing the College's research and teaching profile in the emerging fields of autonomous systems, robotics and mobility cybersecurity, sustainability, virtual reality applications in manufacturing and smart living. The Mechanical Engineering senior capstone course at EMU is a sequence of two 3-credit hour courses delivered fall/winter in the senior year.

The two-course Mechanical Engineering Capstone sequence is focused on applying design of mechanical, electromechanical, thermo-fluid and energy systems, and devices that introduce a new problem-solving approach or innovate a capability that improves peoples' lives. Students are allowed to select from a set of Department-proposed and industry-sponsored projects. Students work in teams of three to five members depending on the expected scope of the capstone project. The establishment of the 1500 square feet VR Lab in the College enhances the access to research tools in VR field for both teaching and research, hence fulfilling one part of the priorities of the College. The VR Lab within the College attracted external equipment funding that facilitated expanding the three-wall system into 4-wall system. The Mechanical Engineering program is a fairly new program and is growing very rapidly. It is expected to offer the capstone sequence in multiple sections of 25 to 30 students in the next two years. Currently, the capstone sequence is being delivered with six capstone projects in the current cohort.

The capstone sequence provides a holistic umbrella to emphasize and apply advanced engineering design knowledge gained during junior year and continued to be learned during senior year. Initially, for the first three cohorts, the capstone sequence utilized the following methods for student prototyping.

1) Physical prototyping utilizing the machine shop and fabrication shop in the Game Above College of Engineering and Technology
2) Rapid prototyping methods utilizing fused deposition modeling (FDM)
3) Virtual reality prototyping

The utilization of VR in place of physical prototyping using a machine shop or fabrication shop started during the fourth cohort of Mechanical Engineering senior capstone classes. Students progress from building conceptual designs, to intermediate detailed designs, and finally detailed designs using CAD tools available in the curriculum.

III. DESCRIPTION OF THE VR LAB AT THE GAME ABOVE COLLEGE OF ENGINEERING AND TECHNOLOGY

The VR lab in the Game Above College of Engineering and Technology is a 1,500 square foot facility that includes a three rear projection rigid screens, 14ft wide by 8.5 ft high. The three walls are arranged into a U-shape as shown in Figure 1. A forth wall is a front project wall represented by the floor. The environment is equipped with four 3D active stereoscopic projectors and nine high end optical tracking cameras to facilitate immersive experience. The environment is also equipped with sophisticated special pointing and user interaction hand-held device. The VR environment is supported by the following software enablers:

1) Complete solid modeling CAD packages commercially utilized by the School's constituents and employers of College's graduates. Currently they are CATIA, SolidWorks, NX, Inventor, and AutoCAD.
2) Embedded add-ins to CAD packages to allow export of CAD content into other non-native format adaptor to game engine software.
3) Game engine software
4) VR enabler software
5) Tracking software

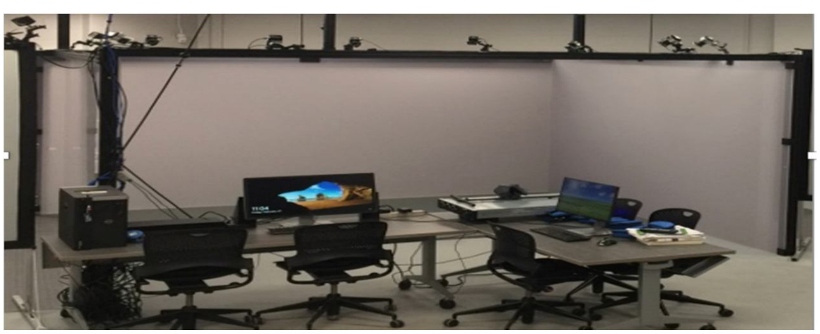

Fig. 1 VR Lab at the GameAbove College of Engineering and Technology at EMU

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The VR Lab has become an integrated part of the ME capstone curriculum during the past two cohorts. Students use the VR Lab as a meeting place to conduct weekly design review sessions. The utilization of the VR lab to is in its experimental phase but has proven effectiveness and widely preferred by ME students over the flat screen design visualization and a valuable precursor to 3D printing.

The process to make CAD content VR-ready has been optimized by many years of VR system integration experience of faculty and graduate students at EMU. The process starts with exporting CAD content into a game-engine compatible format. In our case, to be compatible with Unitiy3D game engine software. The CAD content is then configured in Unity3D and animation and rendering aspects are added in the Game Engine software. The file is then exported into the VR-enabler software which transfers the content to the 3D digital stereoscopic rear projection hardware. Students wear LCD shutter glasses that are optically tracked by an optical tracking system of nine cameras to produce VR content that is immersive. Students use hand-held interaction device to maneuver and walk through the VR content. Figures 2, 3, and 4 show students' interaction with the VR-ready content of their capstone design.

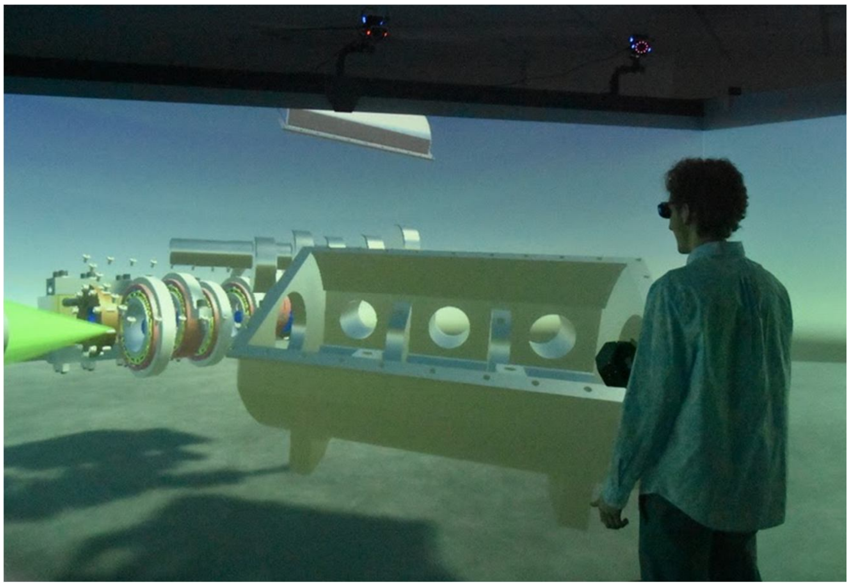

Fig 2 An ME Senior interacting with a VR model of a triplex piston pump

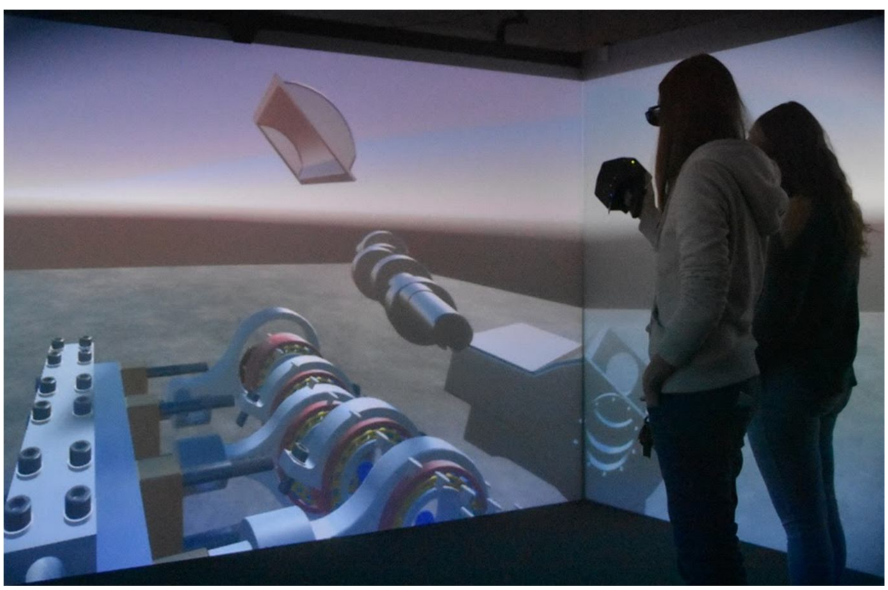

Fig 3 ME students practicing design review meeting using VR Lab

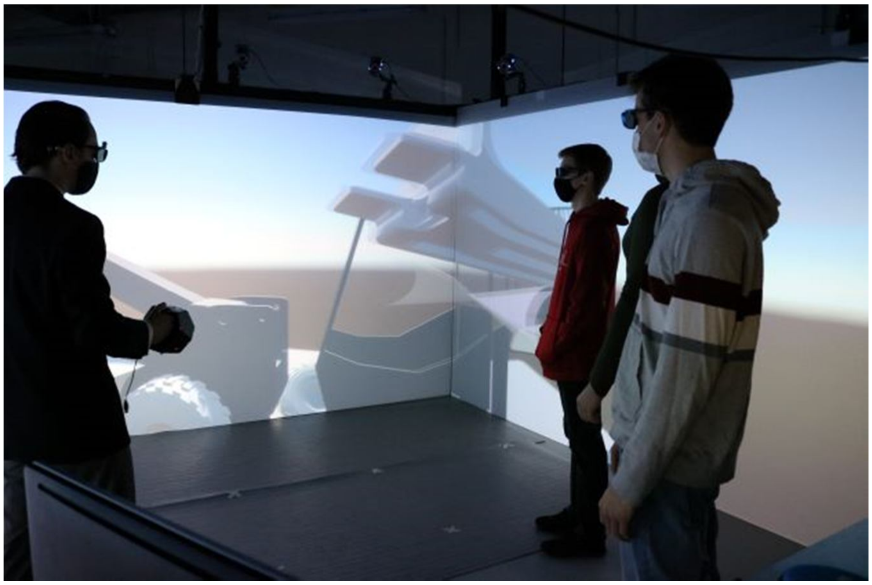
Fig. 4 ME students practicing design review meeting using VR Lab

IV. STUDY

To objectively determine the value of VR to replace conventional or rapid prototyping early in the design process for capstone courses, a study was conducted using ME students in the first semester of the two-semester capstone sequence in Fall 2022. The study probed information related to tying VR effectiveness to the attainment of the course learning outcomes of the Capstone class. The study included a survey which probed responses of students to the following on a scale of strongly disagree, disagree, neutral, agree and strongly disagree.

1) Did you enjoy your experience with the system?
2) Were you successful in controlling and using the system?
3) Is the information provided by the system clear?
4) Did you feel discomfort during your experience with the VR system?
5) I believe using VR hardware would help me be more productive in developing my design prototype.
6) I believe using VR hardware would help me be more effective in developing my design prototype.
7) Using VR hardware would be useful in the engineering design process.
8) Using VR hardware would improve my engineering design.
9) Using VR hardware would enhance my effectiveness in developing new engineering designs.
10) I believe using VR hardware would add time to the design process.
11) I believe it would be easy to get VR hardware to do what I want it to do to improve my design.
12) I believe using VR hardware would be clear and understandable.
13) It would be easy for me to become skillful at using VR hardware.
14) I believe I would have fun using VR hardware.
15) Using VR hardware would be exciting.
16) There is a high likelihood that I will use VR hardware within the foreseeable future for engineering design projects.
17) I intend to use VR hardware within the foreseeable future for engineering design projects.
18) I will use VR hardware within the foreseeable future for engineering design projects.
19) Using VR hardware in the foreseeable future is important to me for engineering design projects.
20) The VR experience provides a better representation of color and texture in a contextual space.
21) The product/part/model in VR helps me to compare it to other product/part/model vs traditional drawings.
22) Light reflection and color available in VR allow for control of Observer Metamerism.
23) Visual texture in VR is perceptibly better than a drawn or sketched alternative.
24) The cost of VR hardware and design software is a concern.

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V. RESULTS

Below are selected results from the study based on student responses to using VR in their capstone design course. There were 25 total responses.

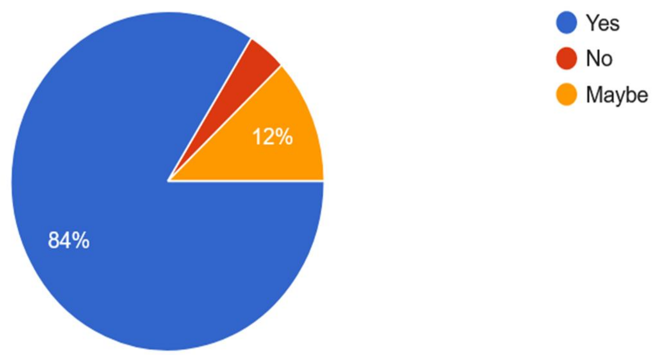

Fig. 5 Did you enjoy your experience with the system?

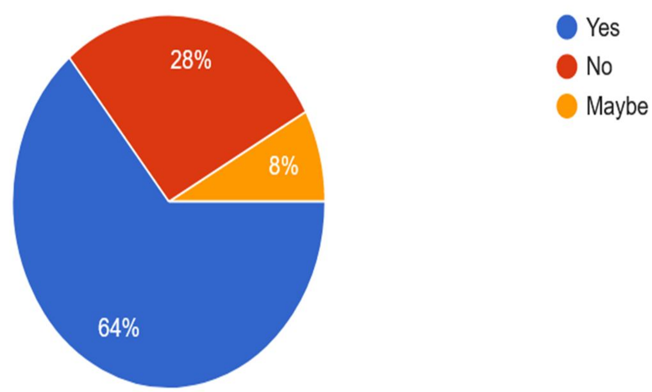

Fig. 6 Were you successful in controlling and using the system?

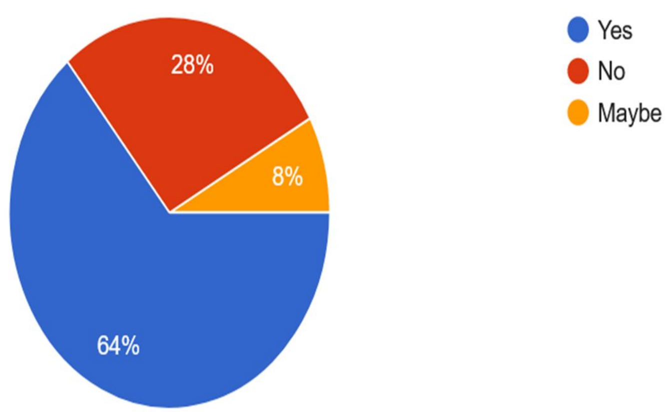

Fig. 7 Is the information provided by the system clear?

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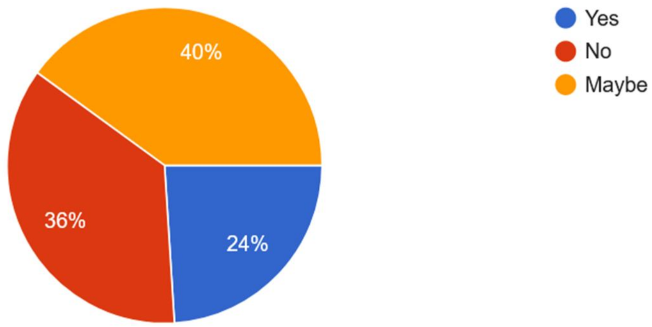

Fig. 8 Did you feel discomfort during your experience with the VR system?

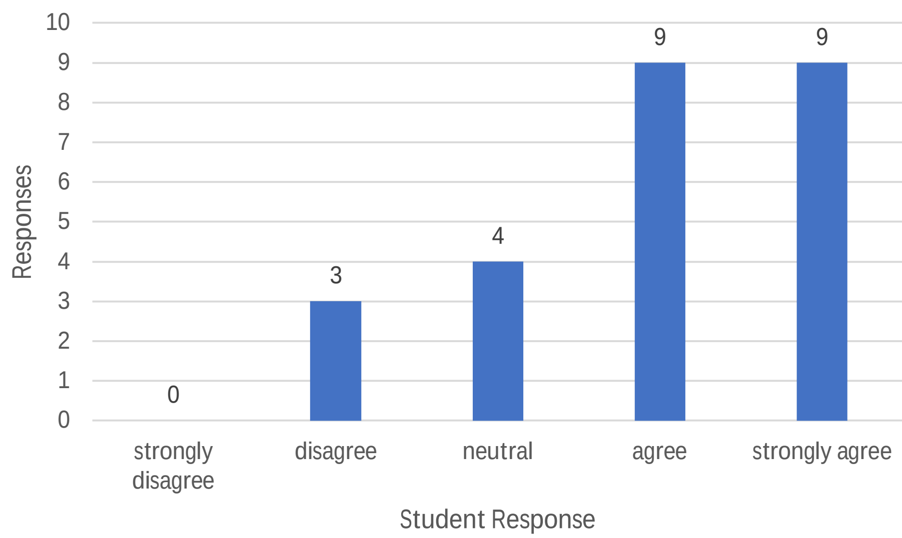

Fig 9. I believe using VR hardware would help me be more productive in developing my design prototype.

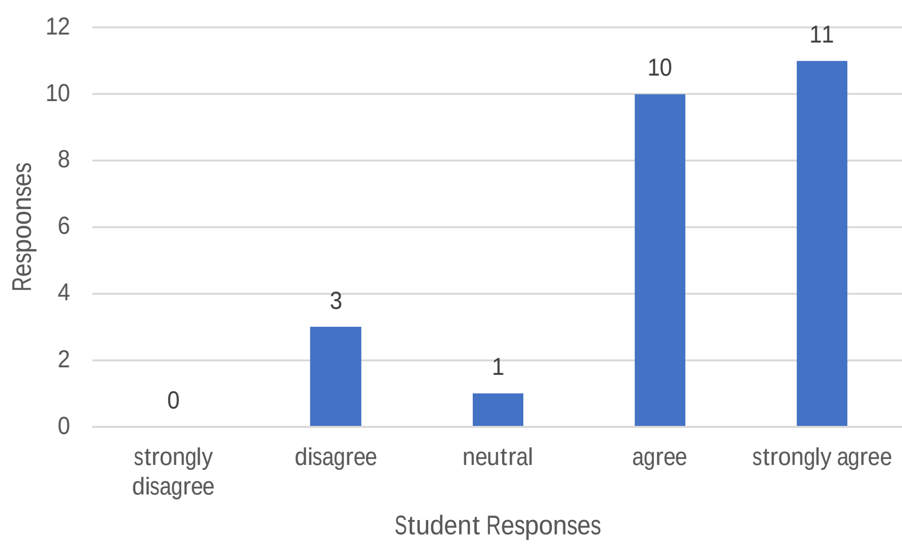

Fig 10. I believe using VR hardware would help me be more effective in developing my design prototype.

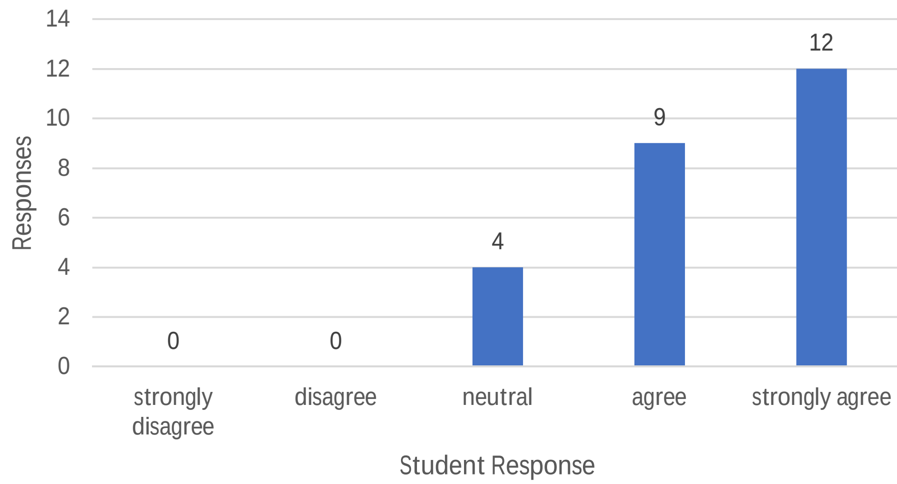

Fig. 11 Using VR hardware would be useful in the engineering design process.

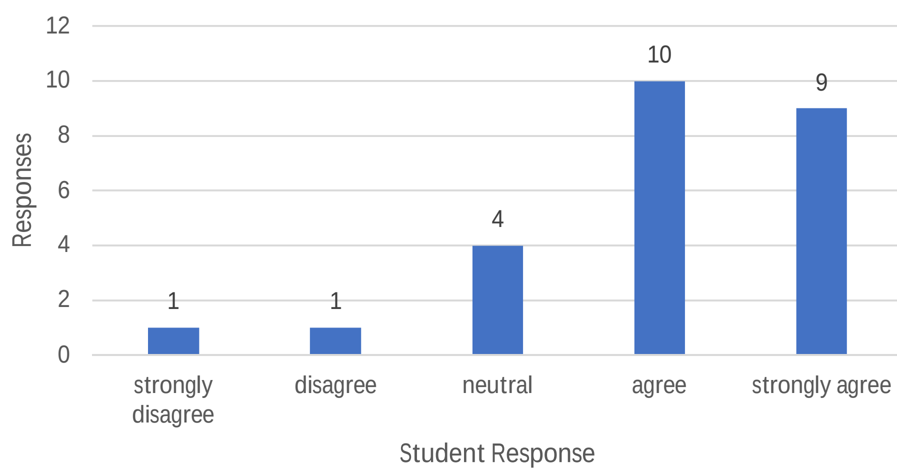

Fig. 12 Using VR hardware would improve my engineering design

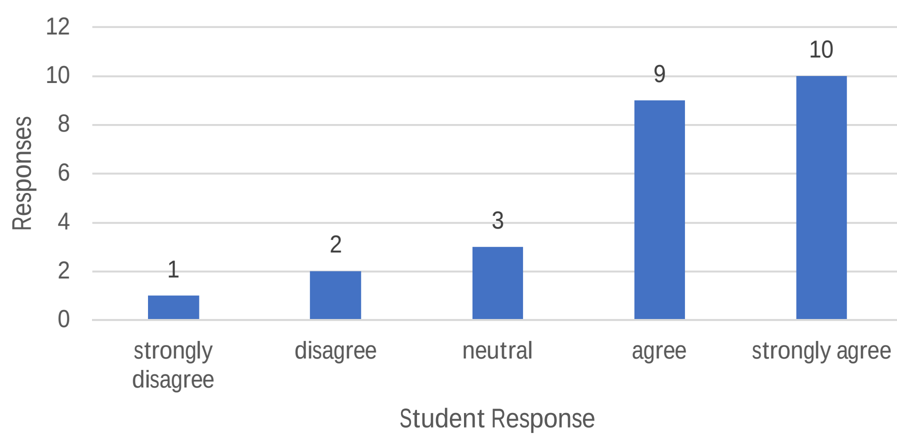

Fig 13. Using VR hardware would enhance my effectiveness in developing new engineering designs.

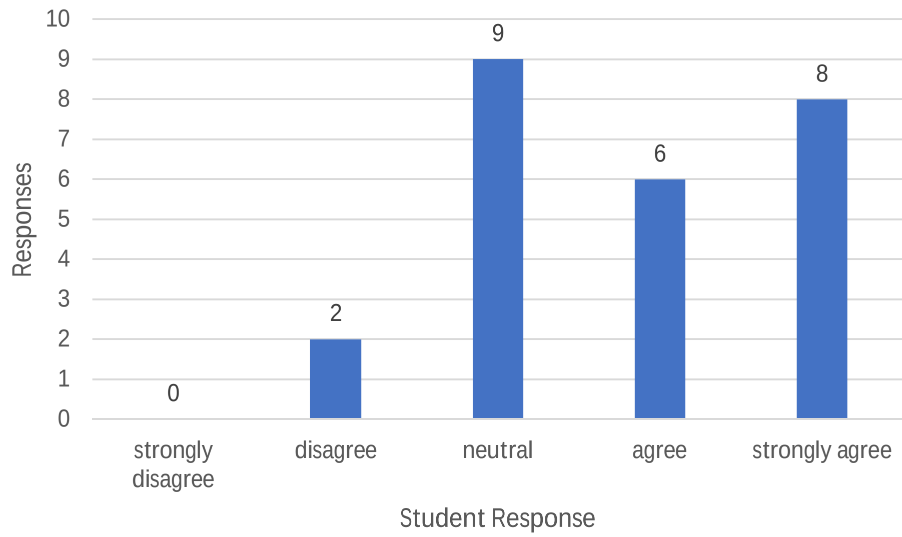

Fig. 14 I believe using VR hardware would add time to the design process.

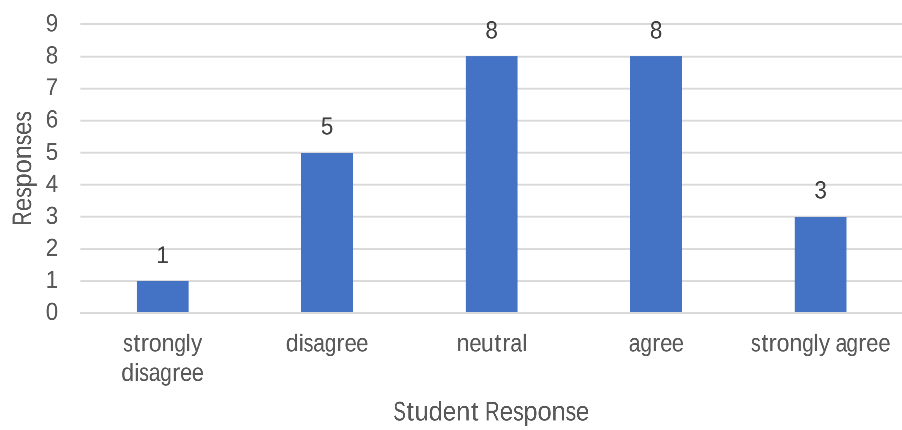

Fig. 15 I believe it would be easy to get VR hardware to do what I want it to do to improve my design.

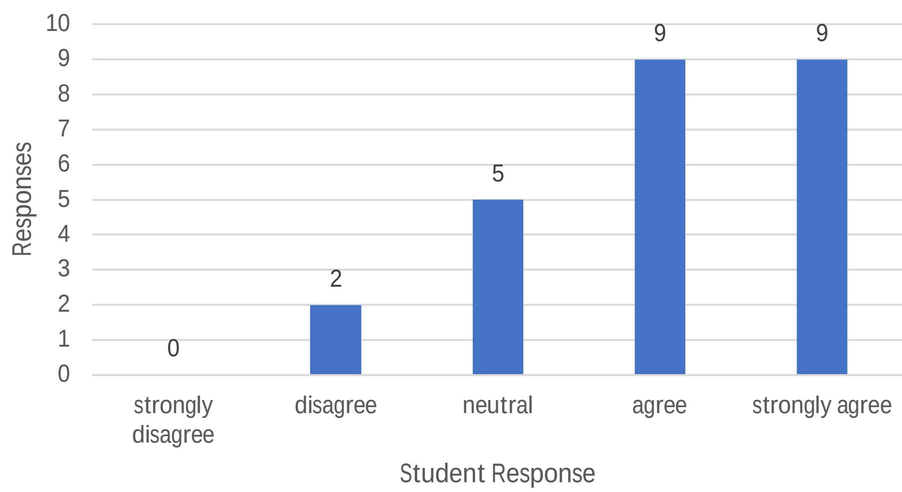

Fig. 16 I believe using VR hardware would be clear and understandable.

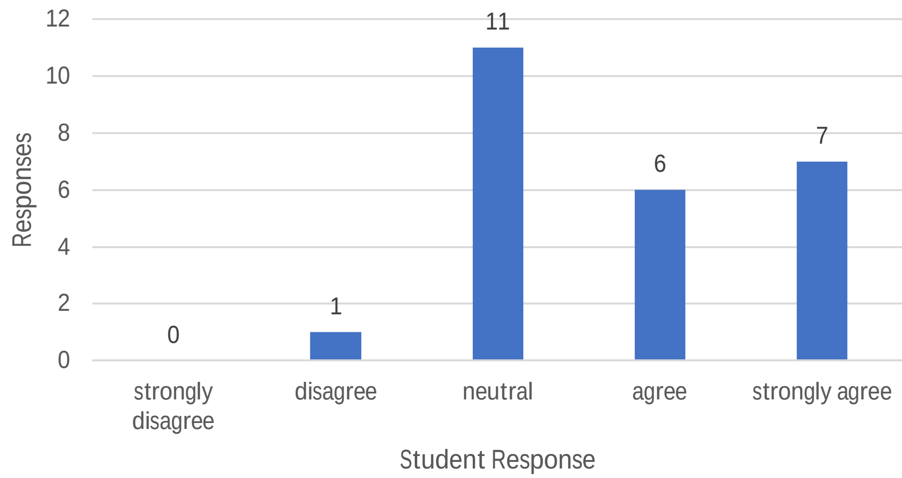

Fig. 17 It would be easy for me to become skillful at using VR hardware.

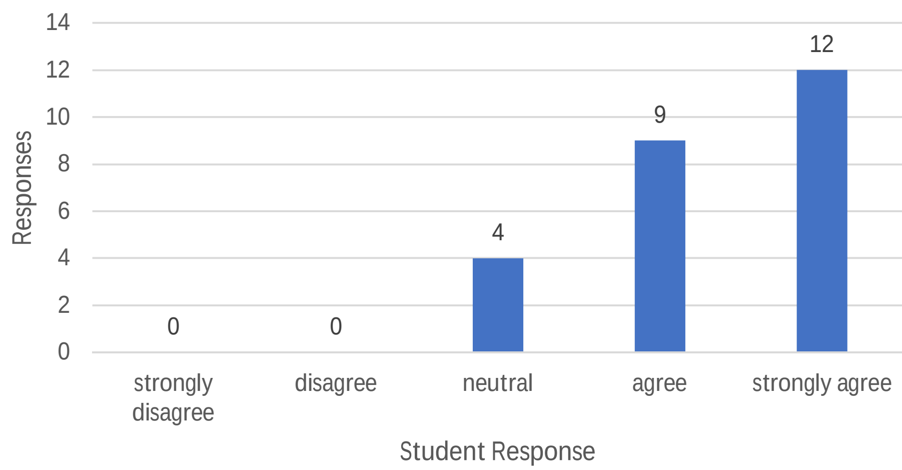

Fig. 18 I believe I would have fun using VR hardware.

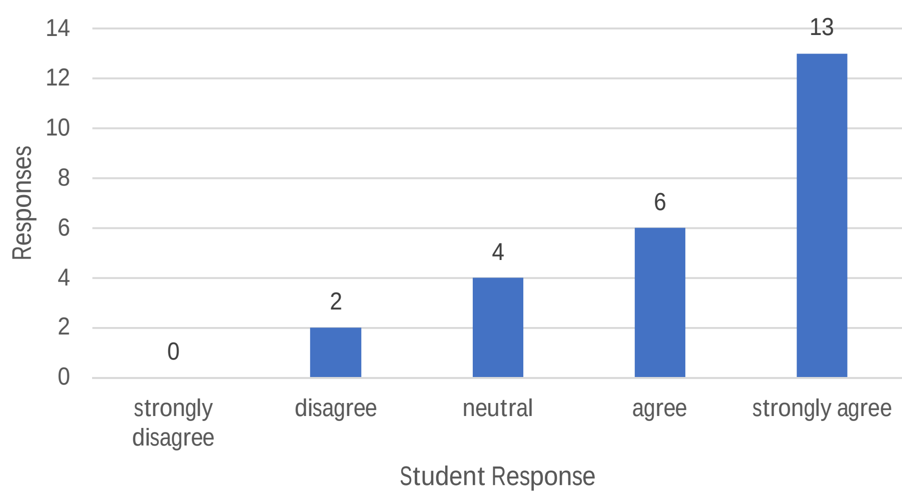

Fig. 19 Using VR would be exciting.

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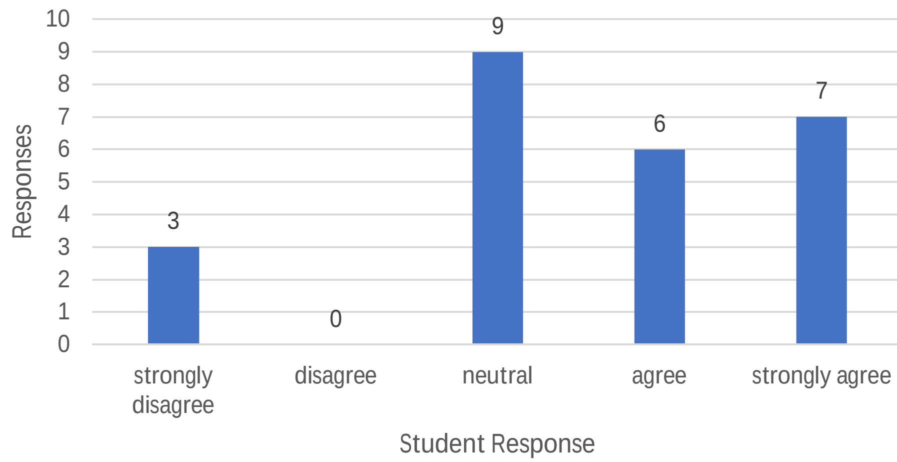

Fig. 20 There is a high likelihood that I will use VR hardware within the foreseeable future for engineering design projects.

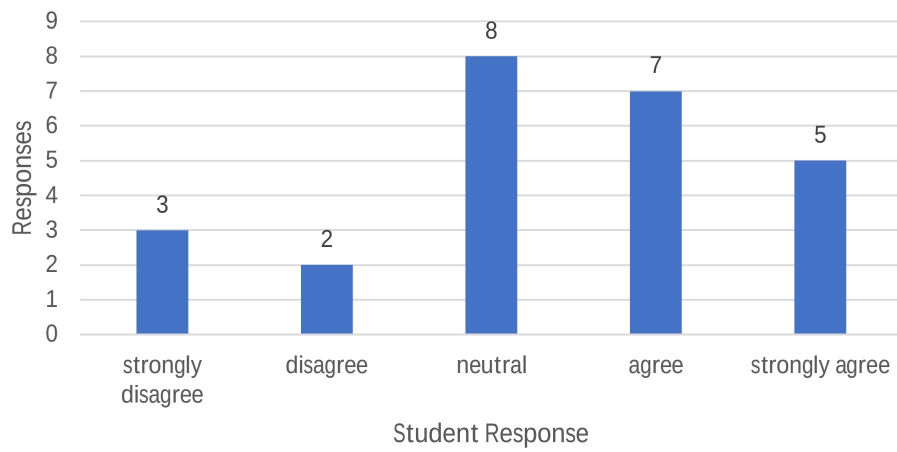

Fig. 21 I intend to use VR hardware within the foreseeable future for engineering design projects.

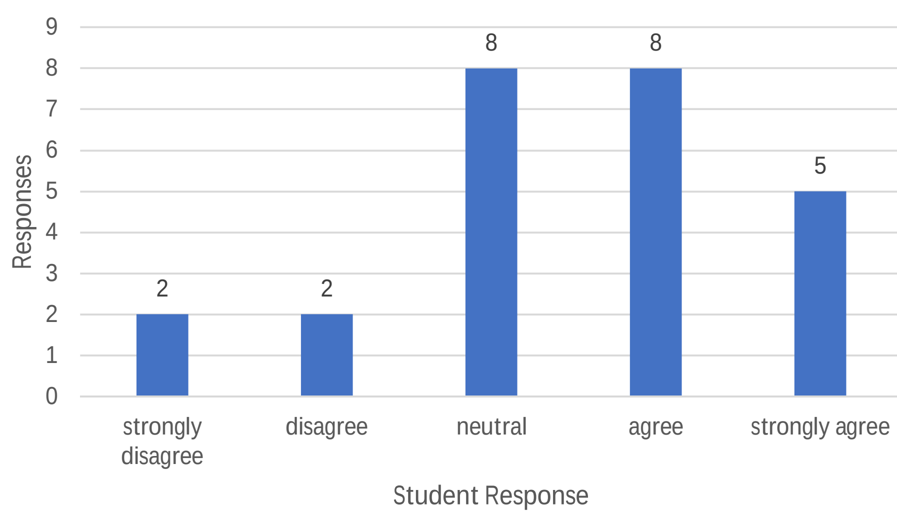

Fig. 22 I will use VR hardware within the foreseeable future for engineering design projects.

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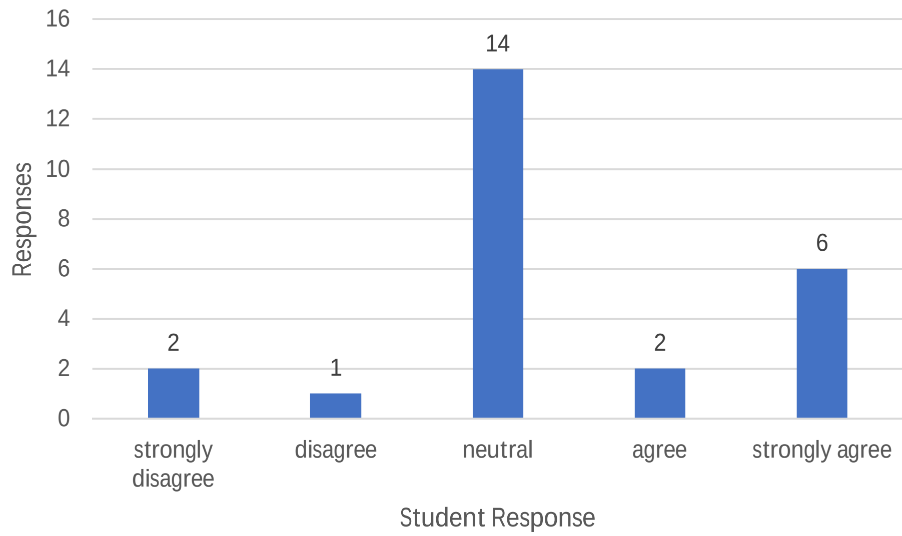

Fig. 23 Using VR hardware in the foreseeable future is important to me for engineering design projects.

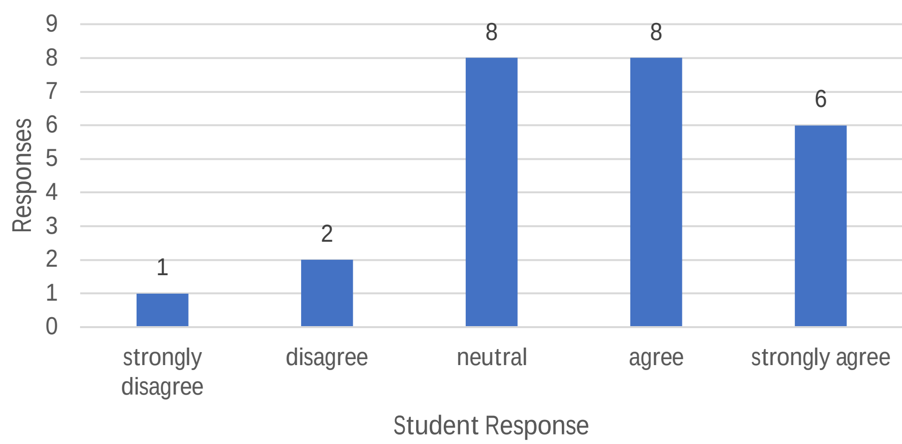

Fig 24. The VR experience provides a better representation of color and texture in a contextual space.

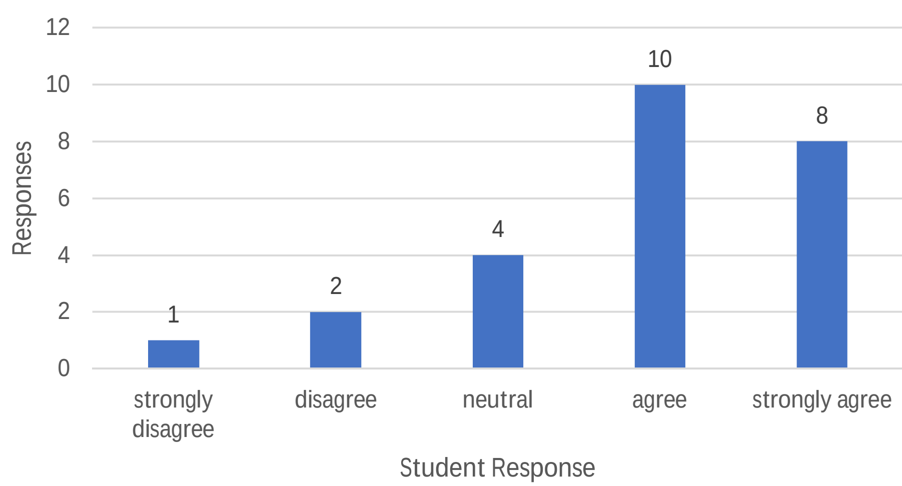

Fig. 25 The product/part/model in VR helps me to compare it to other product/part/model vs traditional drawings.

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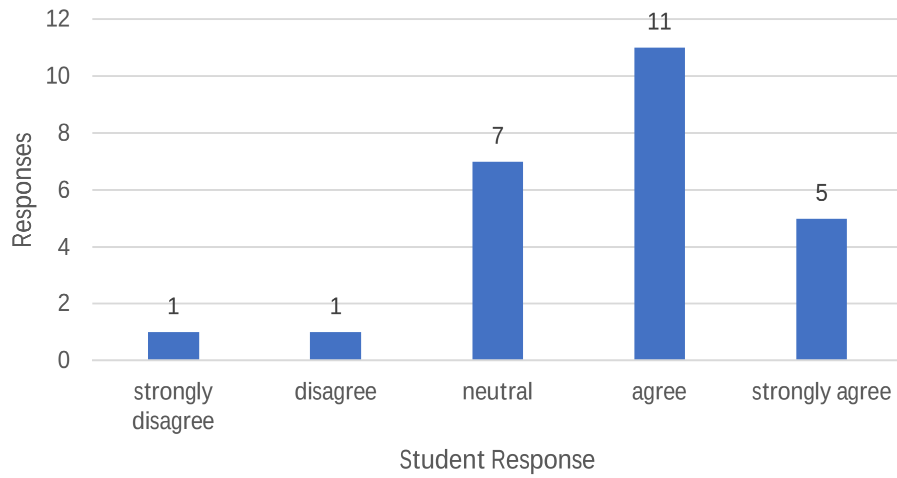

Fig. 26 Light reflection and color available in VR allow for control of Observer Metamerism. (Metamerism is a phenomenon that occurs when two colors appear to match under one lighting condition, but not when the light changes.)

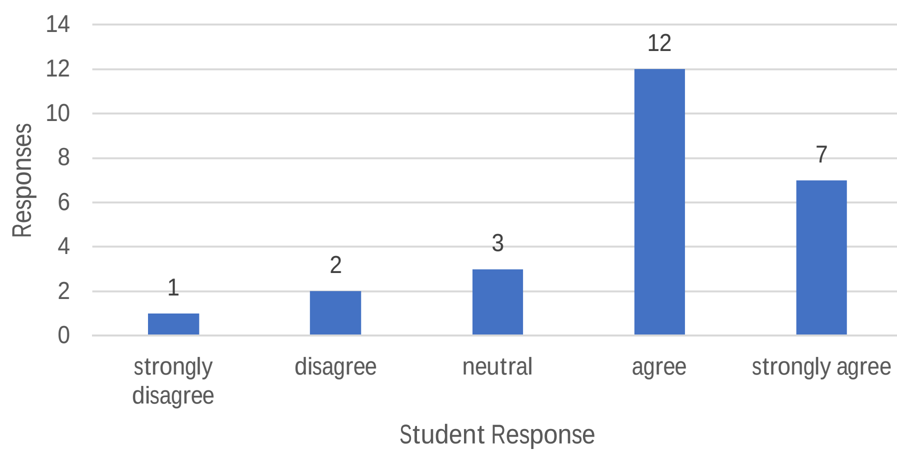

Fig. 27 Visual texture in VR is perceptibly better than a drawn or sketched alternative.

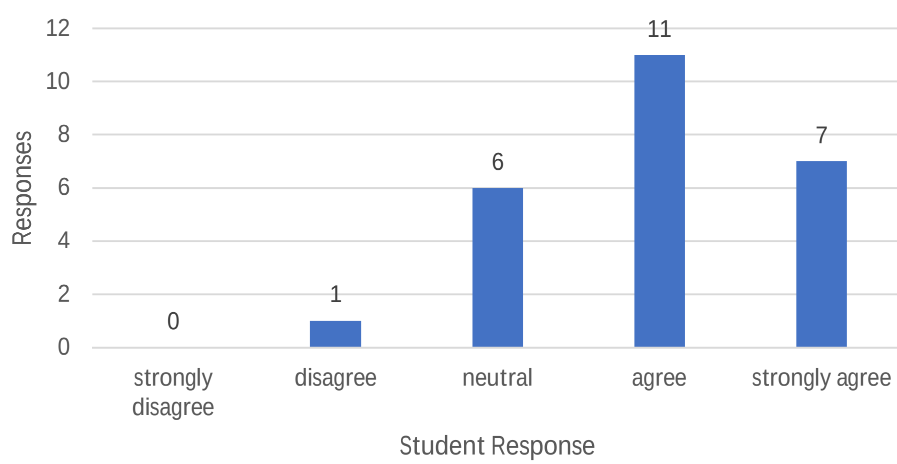

Fig. 28 The cost of VR hardware and design software is a concern.

VI. CONCLUSION

The data demonstrates that students had a good experience using VR and achieved a moderate level of success. In addition, they found it useful for engineering design. Interesting, however, students did not view using VR to improve their design as easy. They also viewed that becoming skilled at VR would not be easy. Additionally, student responses were mixed regarding their intention or desire to use VR in the future for engineering design projects.

In general, the data supports that using VR in the early stages of engineering design capstone classes and during weekly review meetings is of value. It can also postpone physical prototyping until later stages of the design process. Based on the data, additional VR training for students is needed to help the overcome challenges using VR. Additionally, a further, more detailed study is needed to determine the exact areas of VR that students are having difficulty with. This will allow better and more targeted future training and possibly impact how students feel about using VR in the future. In looking forward to the increased use of VR in student capstone courses, pedagogical planning for student success in VR should incorporate the following factors.

1) Ability to Transform CAD content of capstone projects into VR-ready content within a feasible time to allow a cohort of students to utilize the VR lab as a weekly design review medium.
2) Ability to provide adequate fidelity of the visualized content using the framework of VR content fidelity developed by Al-Jundi and Tanbour[9]
3) Ability to simulate animated mechanisms as applicable to capstone project that include moving parts
4) Ability to replace rapid prototyping and 3D printing needs for capstone until the last stages of design review process per semester.

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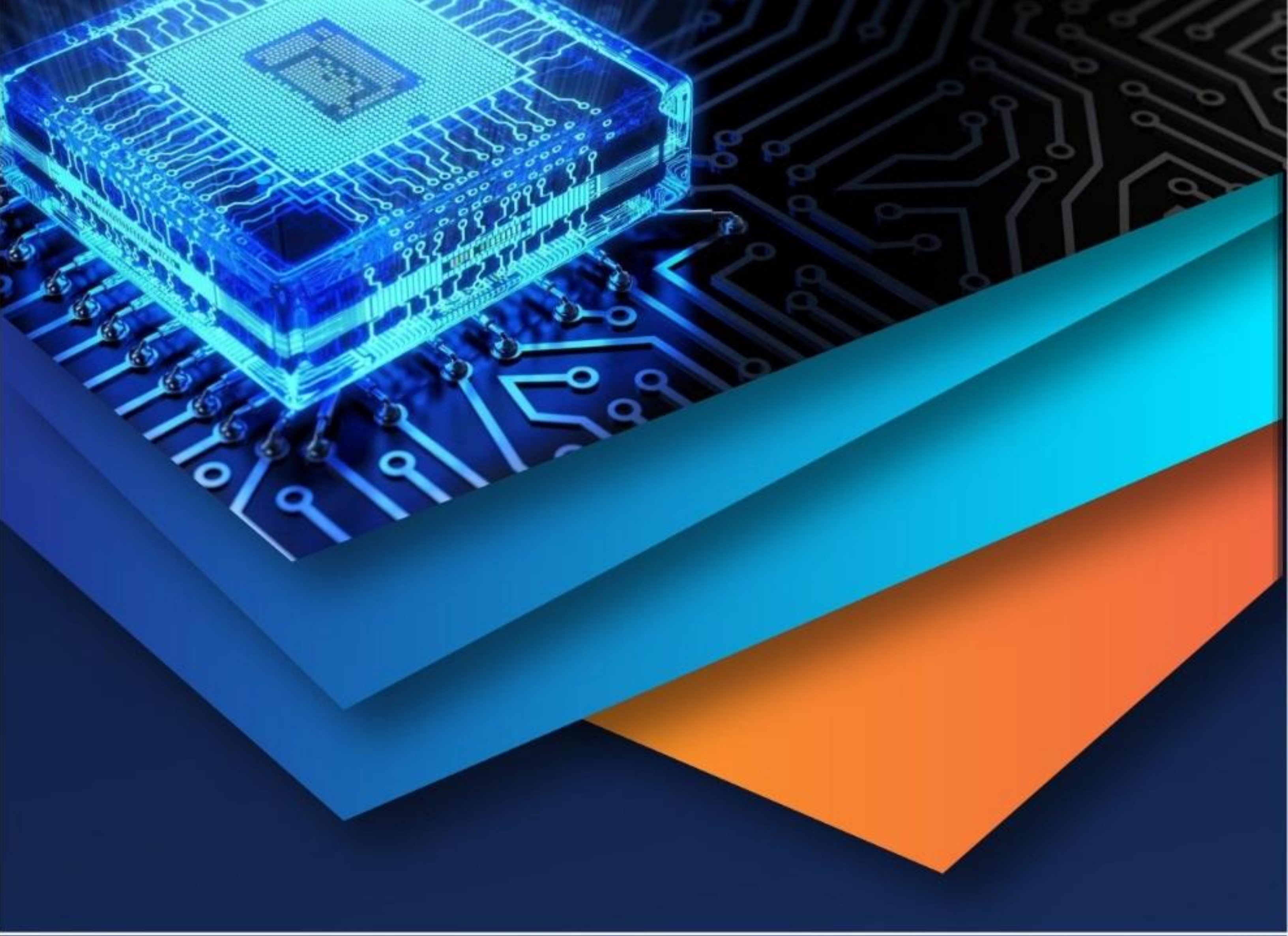

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