PRELIMINARY STUDY ON THE BENEFITS OF VIRTUAL REALITY TECHNOLOGY SUPPORTED BY AN INDUSTRY PARTNER TO ENHANCE MANUFACTURING EDUCATION

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Abstract

Enabling users to immerse themselves in and interact with virtual objects in a simulated 3D environment and to help reduce prototyping costs and shorten product lead time, virtual reality (VR) has become an effective tool for manufacturing industries. Due to the relatively high cost, however, VR technology has not been widely implemented in classroom settings. This paper presents a preliminary study in which VR was introduced to students in a Manufacturing Technology program through lecture, discussions and hands-on lab activities supported by an industry partner. A survey was conducted among the student participants that aimed to evaluate the effects of VR applications in enhancing manufacturing education. The data collected from the participants showed that hands-on VR technology plays a positive role in helping and promoting manufacturing design and production concepts. This study demonstrated a collaboration module on how to utilize industry resources to accommodate new technologies for manufacturing education.

Introduction and Motivation

CAD systems have been widely used both in academia and manufacturing industry communities. However, spatial location of equipment and possible interference between the operator and machinery cannot be fully determined in the CAD system due to its limited capability [1]. In addition, it is difficult for non-technical personnel to understand the CAD system results without previous training or design experience. In particular, if design for manufacturing (DFM) is not fully considered in the product design stage, low manufacturability can become a problem in the stage of production and manufacturing, although the CAD design may appear to be great. This situation could be further complicated by the project complexity, which often requires teamwork where team members may have to work on the same project though physically be separated by region or country. Enabling users to immerse themselves in a virtual world and interact with designed parts and manufacturing equipment, virtual reality (VR) provides a better solution for effective communications among technical and non-technical professionals such as design, manufacturing, application engineers and sales representatives [2]. Virtual reality is a computer-generated 3D virtual environment that allows users to have real-time interactions with objects [3], [4]. Receiving immediate feedback through multi-sensory devices in such an immersive virtual world affords users the perception that they are dealing with real entities in the real world.

VR's theoretical background is an artificial-world construction model proposed by Dr. Ivan Sutherhland that included interactive graphics, force feedback, sound, smell and taste [4]. What really differentiates recent VR technology from the early camera-based Sensorama Simulator is that VR is "an interactive and immersive (with feeling of presence) experience in a simulated world based on computer technologies. Using physical signals in the Sensorama Simulator, wind effects were produced by placing small fans near the user's head. VR, on the other hand, can generate images and collect signals by using computer simulations. VR technology has evolved over the past few decades. The quality and type of VR is a function of the number of levels of immersion. The highest level VR is a full immersive system where the user is totally immersed in the computer-generated world with the help of a head-mounted display (HMD) that provides a stereoscopic view of the scene based on the user's real-time position and orientation. The scene and user's feeling can be enhanced by audio, haptic and sensory interface.

VR is an advanced and comprehensive technology in that it encompasses computer graphics, electronic sensors, computer software and hardware, and the ability to communicate or interface with the peripheral devices. However, VR does not just belong to computer professionals; instead its scope of applications has been extended across a large spectrum [2] from scientific research/simulation to entertainment. Because of presenting a 3D graphic interface, VR technology plays a significant role in scientific visualization so that the visual representation of abstract systems such as wind-tunnel flow and thermal distribution, weather forecast, molecular chemistry models and solar systems can be expressed vividly. This makes understanding the abstract system no longer a headache. Being a super visualization tool, virtual reality has also found applications in education and training in a variety of areas like military, medical surgery, equipment operation and maintenance, and especially in the field of engineering/technology education [5-7]. Engineering education involves abstract subject knowledge, for instance in engineering design and analysis where there would be a strong need to turn pure lecture-based learning into experiential learning so that students get a deeper and more robust understanding of the concepts [8]. VR technology, allowing extreme close-up examination of an object with detailed features, motivates and engages students to proceed through an experience on their own. In addition, the interaction between users and the entities in the VR system encourages active participation rather than passivity [9].

Manufacturing is a part of the engineering discipline. Manufacturing basically comprises the following types of engineering tasks: product design, production planning, implementation and operation of the actual production system. These four tasks could benefit from the application of VR through user interactions with real-size product models in the 3D computer-generated factory layout equipped with real-size machine tools and material handling equipment. This way, design flaws could be identified earlier and manufacturing sequences could be optimized by means of virtual prototyping, thus saving substantial manufacturing costs.

Research and development on virtual reality started in the 1960s. The initial players were top research-intensive universities and federal government-sponsored research institutions since constructing a VR system needs expensive high-processing-speed computing devices. From the 1990s, the big brand-name manufacturing companies such as Boeing, Caterpillar, Ford and John Deere have been adapting VR technology for design interference detection, concept and product prototyping, manufacturing process planning and optimization, and ergonomic analyses [10-12]. Besides regular high-processing-speed computer and graphic cards, some other advanced technical components including hardware and software must be integrated and interfaced in order for the VR system to function as desired. Constructing a virtual reality system requires components such as head-mounted displays (HMD), data gloves, motion-tracking sensors, simulator joystick and rendering software systems that will generate visual, audio and other sensations to users. These components are very expensive. A high-resolution HMD could cost more than $10,000. In addition, specially trained personal must be available to support the VR system, which will make the application of this technology even more costly.

Currently, manufacturing engineering/technology education is facing many challenges in the U.S. One of these challenges is keeping manufacturing education up-to-date by investing in advanced technologies. However, the lack of educational resources cannot accommodate the emerging learning needs [13], [14]. VR technology has not been widely utilized in manufacturing technology/engineering educational institutions. Therefore, there are limited reports in the literature on its educational effect in manufacturing disciplines. Collaboration between academia and industrial partners can bridge this gap [14]. The following session presents a preliminary study that explores the benefits of VR technology supported by an industrial partner for manufacturing technology education.

Application of Virtual Reality for Manufacturing Education

The Manufacturing Technology (MT) program is housed in the Department of Industrial Technology at the University of Northern Iowa (UNI). Located in the northeast part of Iowa, UNI is primarily an undergraduate state university with approximately 13,000 students. In its over one hundred -year history, the Department of Industrial Technology has established strong partnerships with local industries. Graduates from UNI's Manufacturing Technology program provide a skilled employee pool for the local manufacturing companies. This includes the manufacturing of aircraft, large off-road equipment, wind-power devices, general industrial equipment, furniture and other consumer products.

The MT Program provides a wide range of training for manufacturing professionals by offering a variety of courses such as design, manufacturing automation, production planning and control, and quality management. The computer lab has design and manufacturing software packages such as Autodesk® AutoCAD® and Inventor®, Pro-Engineer®, Mastercam® and Vericut® to implement 2D and 3D modeling and simulation. The Production Lab has full capabilities for a variety of machining operations. Turning, milling, punching, shearing, grinding and casting operations can be conducted in the lab. Both desktop-scale and full industrial-sized CNC machines and 3D printers can be used by students to produce products or prototype designs. However, the immersive VR lab facility is still at the unreachable level at UNI due to the university's budget constraints as well as its high capital investment and operational costs. Fortunately, there are several VR labs at local industries. One particular local manufacturing company, whose main product is off-road vehicles, possesses three VR labs at different immersion levels by integrating varied sensing techniques. UNI's MT program has a long-standing collaboration with this company–some of its fulltime employees come back to school to update their knowledge and pursue a higher degree, and many of the enrolled students work part-time for this company and are offered full-time positions right after graduation. The MT students learn CAD/CAM and other computer simulations required by the program of study, but do not have an opportunity to directly experience VR simulation at UNI's lab. Based on recent technological trends and discussions in the Manufacturing Program Industrial Advisory Board meetings, the instructor added a module on VR and its application in one advanced manufacturing course.

The fundamentals of VR were introduced to a senior-level manufacturing course, including scientific definition, historical development and evolution, basic components both in hardware and software, advantages and disadvantages along with general applications. Special interests were given to the VR application in manufacturing and the successful examples that have used VR technology for new product design and ergonomic analysis. To supplement the conceptual ideas constructed during lectures, a special field trip was organized to visit one of the VR labs of the off-road equipment manufacturing company in the local community so that students could experience the immersive computer-generated virtual world. The VR lab that the class visited had hands-on activities in a three-wall immersive virtual system that utilizes optical sensors to track user motions.

The engineer in charge of the lab facilities is also interested in promoting VR technology and using it for training the company's employees. After going through the company's proprietary protocol and obtaining permission, the students enrolled in the Advanced Manufacturing Processes class were able to visit the VR lab and receive hands-on experience with the VR models and entities.

Each individual student was able to experience three different levels of virtual-reality activities. One activity was that students tried several pieces of haptic computer applications. For example, the user could feel the bouncing effect when a computer mouse pushed a computer-generated robbery trampoline and the user could feel the pressure and the sliding when a computer mouse was clicking on the spherical surface of a computer-generated solid ball. The second activity was that each individual student was able to wear the motion tracking device, stand in the three-wall CAVE system and experience and manipulate one of the 3D virtual models provided by the VR lab. The 3D virtual models included a big off-road vehicle, a wheel mounting machine for the off-road vehicle, a virtual factory layout and assemblies of engine and other components. The third activity was to manipulate a skateboard assembly model that was created by a UNI MT student. In Figure 1, a student was riding in the virtual wheel mounting machine, trying to manipulate the functions provided by the wheel mounting machine. After this field trip, a survey was conducted among the student participants based on the request from the industrial partner; meanwhile, the survey was used to test the effectiveness of this activity impacting students' perception about virtual reality and its application in manufacturing.

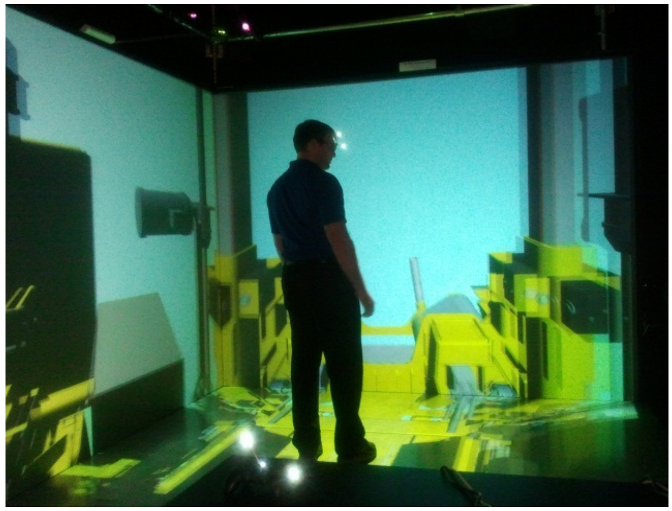


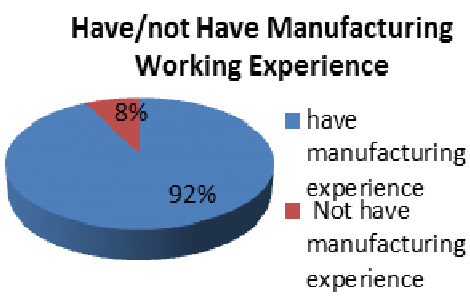
Figure 1. A Student Experienced a Three-Wall CAVE Virtual Reality System

Effectiveness Analysis of Student Perceptions on Virtual Reality in Manufacturing Education

The survey consisted of three parts: 1) general demographical questions about the student participants; 2) descriptive evaluation of student perception on VR technology and its impact on manufacturing education; 3) quantitative evaluation of student perceptions on VR technology, its application and impact on manufacturing education.

Survey Demographics

There were 13 students in this course. Of the 13 enrolled students, nine were undergraduates majoring in Manufacturing Technology, and four were graduate students who had different backgrounds in Electronic Engineering, Electronic Engineering Technology, Mathematics and Industrial Engineering. The undergraduate and graduate students took this course to meet the requirement set by their program of study. Having introductory-level courses and a CAD/CAM background for the undergraduate students, this required course would deepen their understanding on the advanced manufacturing aspects other than traditional manufacturing processes. For graduate students, this course served as an elective course to broaden their understanding of manufacturing industries in general. None of the graduate students had taken an introductory-level manufacturing course, but they were assigned to read a lot of chapters on basic manufacturing processes and operations. The graduate students had almost no experience in using CAD/CAM packages because of their non-manufacturing academic background. A vast majority of the students were working part-time or full-time and had some work experience related to the manufacturing industry. Only one student reported never having heard of virtual reality before and the rest of them indicated that they had heard this term in formal or informal settings. Five out of the 13 students mentioned that they had had a tour in another VR lab facility of this company from other class activities; however, that previous tour was not interactive. Three students had touched VR components through recreation or entertainment games. The survey demographic results are summarized in Figure 2.



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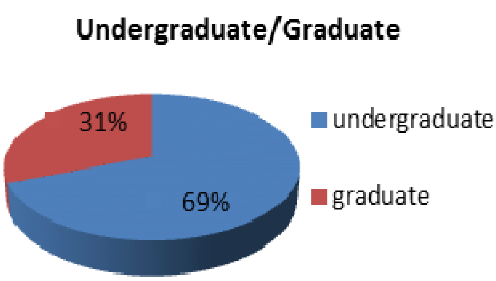

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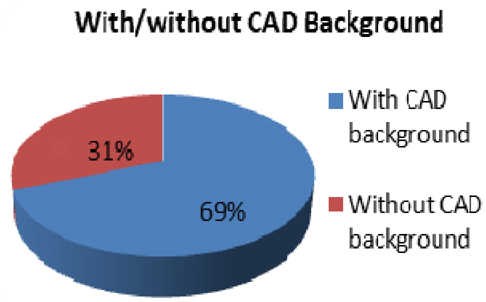

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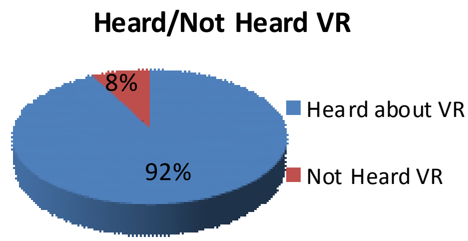

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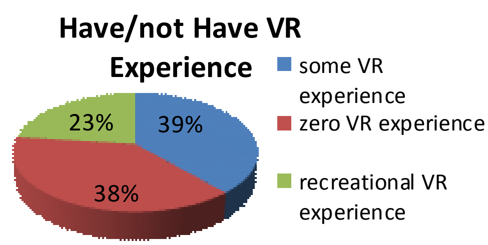

(e)

Figure 2. Demographic Information for the Survey Students

Descriptive Evaluation of Student Perceptions of VR on Manufacturing Education

The MT program at UNI and this industry would like to establish a long-term partnership, especially wanting to explore a cooperation through which the faculty and students could use the industry's VR facility for involving/working on real industry manufacturing projects in the future. Therefore the following questions were included in the survey in order to solicit ideas on how to improve VR-related activities in the future:

- Overall, how do you think the VR demo went?
- Was it a valuable experience for students?
- What would you like to change?
- Do you like to request future activities like this one?
- Any other comments?

From the students' responses, all students thought that the tour to the VR lab was very beneficial in understanding the usefulness of VR to manufacturing. They really appreciated the hands-on opportunity arranged in this tour, which provided an excellent opportunity for the students to see how such an advanced technology has actually been implemented in manufacturing design and production, particularly in the local manufacturing industry. All participants had a consensus that it was valuable to see, feel and touch this technology. After the tour, they felt it became easier to understand what VR is, why it is useful and how it is used. The students agreed that this field trip brought VR technology closer to them because it was not just a story read from the Internet, but rather a real application in the local manufacturing industry. Some of the students said "no need to change the current setup" or "keep as it is", and some recommended that they would like to see specific examples of where/how the company used this technology for evaluating or virtual prototyping a part design or an assembly design. All students thought these activities should be scheduled for future students.

The students' understanding of VR technology before and after the lecture was also evaluated. Accordingly, more questions were included in the survey as below:

- What do you learn from the VR topic and the field trip?
- Are there any changes in terms of your understanding about virtual reality before and after the VR lecture discussion and the factory VR tour?
- What specific applications in the manufacturing field do you see/think that the VR technology would be most suitable for?
- What applications in other fields besides manufacturing do you see/think that the VR technology would be suitable for?

Virtual reality appears to be a popular term because it is not only used in the academic field but also in entertainment such as 3D movies and video games. However, all students indicated that their perception and understanding of virtual reality changed to some degree. The very representative tone from the student responses is that before the field trip, students thought VR was a simulation tool similar to regular CAD/CAM software. This incorrect perception is not unusual. VR and CAD/CAM, in fact, are not even correctly distinguished in the literature [15]. Some students thought that VR would be just a more interesting way to present things or would be more like a 3D movie. After the field trip, students reported that they could "better picture what interactive VR is really like". The most impressive feature the students experienced was that they could walk through in the immersive virtual world and they could have real-time interactions with the designed product model. Students commented that both the VR technology and the tour were amazing.

The lecture, along with the field trip, broadened the students' understanding that VR technology has a wide variety of applications in scientific visualization, architecture design and engineering and technology education. From a manufacturing perspective, the biggest gain was that students had a better awareness of the fact that VR has a lot of potential in manufacturing applications such as product design, ergonomic analysis, assembly sequence optimization, etc. VR technology has been implemented and applied in manufacturing for almost two decades, but the majority of the students did not understand this technology and its application potential until they had this hands-on field trip. Due to the capability of doing virtual prototyping and testing, students clearly understood it could help prevent and catch design faults that might lead to problems in production. It is also an efficient and greener approach in that VR could possibly save companies a significant amount of money by reducing physical prototypes. One student even predicted "it will become more advanced and useful within the next 20 years". One graduate student reported that he had learned basic information about VR including definition, history and some applications. After the field trip, he comprehended better because he had the chance to physically use and test the VR hardware. His theoretical knowledge turned into practical knowledge.

Quantitative Evaluation of Student Perceptions of VR on Manufacturing Education

In the quantitative evaluation, there were two questions. The first one attempted to find out how students felt about VR's effectiveness on manufacturing technology education by using a 5-point Likert scale (5-Strongly Agree, 4-Agree, 3-Neither Agree nor Disagree, 2-Disagree, 1-Strongly Disagree). The descriptive statistics are listed in Table 1. A majority of the students strongly agreed that virtual reality made comprehension easier and was attractive to them. More than 50% of the students strongly agreed that VR technology facilitated visual thinking and induced people to be active in this environment. Due to this, it is reasonable that students felt that virtual reality made memorization easier and learning faster. Students also responded that in the VR world, they needed to concentrate more in order to orient themselves with the environment and objects. This may be caused by the fact that VR was a new technology to the majority of the participating students, and they were not used to the way it presented entities.

Students' responses to portions of the questionnaire that asked if VR "is tiring", "too involving" or "may be confusing", were in-between neutral and disagree. However, it appeared that there were more variations among students' opinions on these last three items since there were relatively larger standard deviations. The t-test of whether there was a significant difference between the undergraduate and graduate student groups revealed that the two student groups' perceptions about VR educational effectiveness were the same except on one question (virtual reality may be too involving). With the lowest overall average (2.08) for this question, the average for the graduates' response was 3 and the average for the undergraduates was 1.67. These numbers indicated that undergraduate students disagreed with this statement and the graduate students had a neutral attitude. In addition, the Pearson Correlations showed that the academic status of graduate or undergraduate did not bring correlations with their perception about VR, except that in question k there was a weak correlation, which presented the same result as the t-test.

Another survey using a 5-point Likert scale (5-Very Interested, 4-Interested, 3-Somewhat Interested, 2-Little Interested, 1-Not Interested at All) investigated how VR technology could motivate student learning in different applications. The descriptive statistics results are listed in Table 2. The means for the five individual questions were about 4, which indicated that students were all generally interested in participating in these activities if they were available. There were no significant differences between the two student groups, but the standard deviations of these questions were relatively large compared with the questions presented in Table 1. A detailed examination of the response data found that the graduate students had more consistent responses, and they selected 5, 4 or 3, while the undergraduate students showed a big variation —their responses were spread from 2 to 5. The responses are shown in Figure 3. The Pearson correlations between student status and response were all below 0.5, which means that there were no clear correlations. Graduate and undergraduate students all showed an interest in using VR for manufacturing education.

Table 1. Descriptive Statistics of Student Perception of VR on Manufacturing Education

Virtual Reality…					
	Mean	Std. dev	P-values	Difference between G and UG	Pearson Correlation
a. is attractive	4.46	0.52	0.867	No	0.051
b. allows an immediate check of what has been studied	4	1.15	0.348	No	0.284
c. facilitates persons who have a visual thinking style	4.31	0.48	0.128	No	-0.444
d. induces persons to be active	4.08	1.04	0.490	No	-0.211
e. makes the comprehension easier	4.54	0.66	0.737	No	-0.103
f. requires concentration	3.92	0.86	0.644	No	-0.142
g. makes the memorization easier	3.92	0.76	0.640	No	-0.144
h. allows to learn fast	3.85	0.99	0.763	No	0.093
i. facilitates persons who have an intuitive thinking style	3.92	0.86	0.471	No	-0.220
j. is tiring	2.31	1.82	0.721	No	0.115
k. may be too involving	2.08	1.12	0.057	yes	0.562
l. may be confusing	2.77	1.24	0.555	No	-0.190

Table 2. Descriptive Statistics of Possible Ways that VR Can Motive Student Learning

	In the future, students are interested in	Mean	Std. dev	P-values	Difference between G and UG	Pearson Correlation
a.	Working on class projects in the VR environment	3.92	1.12	0.180	No	0.396
b.	Working on industrial projects in the VR environment to solve real world solve	3.92	0.86	0.937	No	0.024
c.	Attending manufacturing labs in the VR environment	4.08	1.12	0.533	No	0.191
d.	Attending VR factory or facility tours that illustrate best practices running a factory	4.31	1.03	0.401	No	0.255
e.	Playing roles in manufacturing simulations that illustrate processes and best practices of running a supply chain in the VR environment	3.92	1.26	0.122	No	0.451

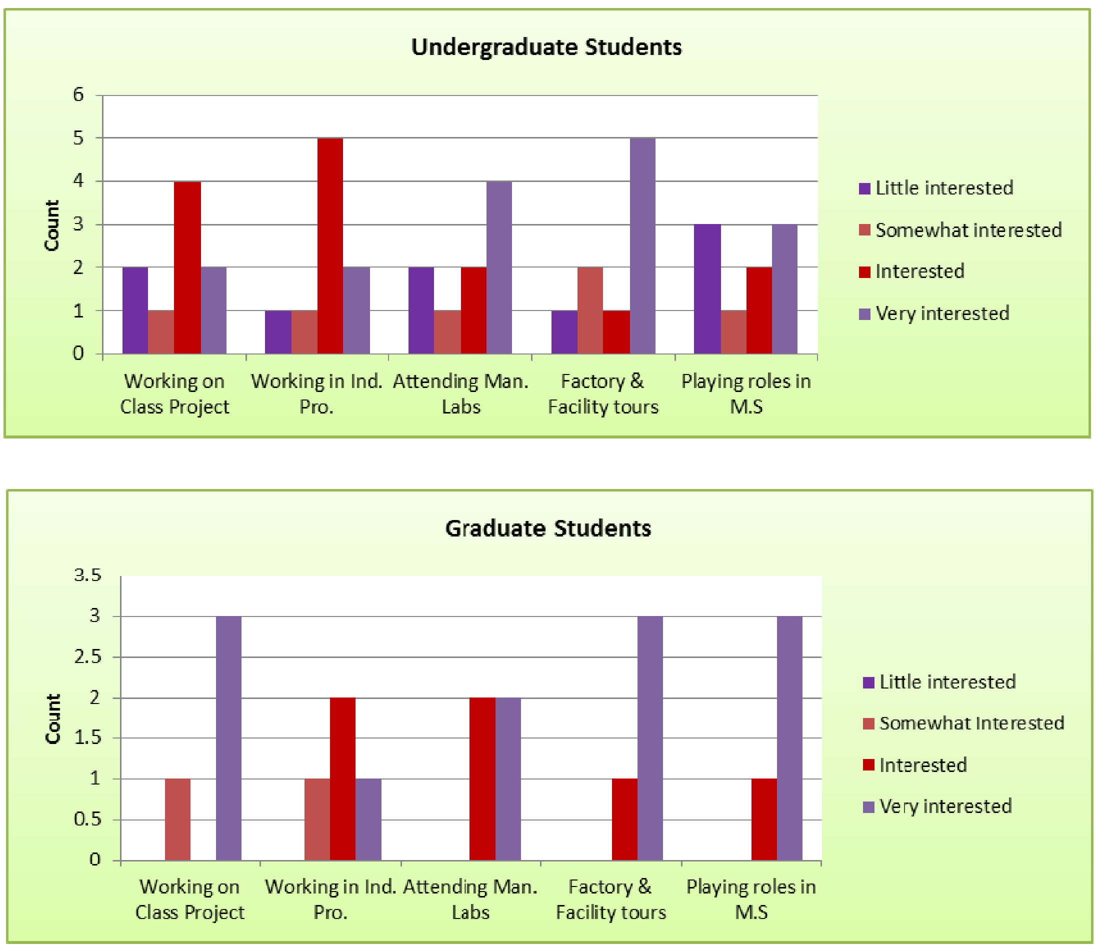

Figure 3. Graduate and Undergraduate Student Response Distribution on How VR Can Motivate Student Learning

Limitations

The limitations of this study include the capacity of the VR lab and the student sample size. The class size was limited to 13 students, which limits the generalization of the findings. The study was designed to let students have hands-on experience with VR technologies. The VR lab that the class visited and which had hands-on activities was a three-wall immersive virtual system that utilized optical sensors to tract user motions. Each student spent 15 to 20 minutes on the VR lab to experience all the facilities. As shown in Figure 1, only one student at a time could be immersed in the virtual environment due to the nature of the technology. In this respect, the capacity of the VR lab to provide hands-on experience to students was limited. When the same course is offered next time, research endeavors could include an assessment of students' perspective about VR with a larger sample size by repeating the same study questions for different groups of students.

Conclusions

The following is a summary of the conclusions from this study:

- Although it has existed and has been applied by industries for more than a decade, there is still a way to go before VR technology can be adapted to facilitate ordinary manufacturing teaching activities due to resource constraints.
- The survey results indicate that VR technology is helpful to induce learners to be active and interactive. Virtual reality's ability in easily visualizing structures makes manufacturing product design easier and facilitates better learning.
- Students were satisfied with this virtual-reality topic and with the virtual-reality lab facility tour supported by the industry partner. The lectures and hands-on activities were effective in helping students understand VR technology and its application in manufacturing.
- Virtual reality is an attractive technology to students. To manufacturing technology students, the introduction and application of VR technology does not necessarily involve a lot of computer science theory; therefore, it can be understood properly by a large audience as an auxiliary tool in manufacturing education.
- Virtual reality can promote manufacturing learning in that students are willing to try and experience class projects or real industry projects using VR technology. The knowledge of computer science may not be necessary, but CAD/CAM should be prepared if a manufacturing engineering/ technology graduate would like to apply virtual reality or work on related projects.
- It is necessary to repeat the same questions for future students who take the same course in order to verify the study's findings due to the small size of the current sample.

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