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Session 3B

Preliminary Testing of a Virtual Reality Based Educational Module for Safety and Hazard Evaluation Training

John T. Bell
H. Scott Fogler

ABSTRACT

Virtual reality, VR, offers intriguing possibilities as an educational tool through its ability to place students into environments not otherwise accessible. However it is yet to be determined which subjects are best suited to benefit from virtual reality, and how to apply the technology to yield the most benefits. In order to explore these questions, a number of virtual reality based educational modules are being developed in the Chemical Engineering department at the University of Michigan. This paper describes the first student evaluations of one such module, using a virtual reality based simulation to aid students in performing a safety and hazard evaluation of a chemical production facility. The simulation is based upon photos and other information gathered from an actual chemical plant, but is not intended to be a completely accurate reproduction for proprietary reasons. One hundred fifty-five students from a senior plant design course were asked to analyze the safety and hazards of the facility from a detailed written description, and to evaluate the virtual reality model. Half of the students were asked to complete their safety analysis prior to running the simulation, and the other half were to use the simulation to complete their safety analysis. Ten students were selected to tour the chemical plant upon which the simulation was based.

BACKGROUND

Today's students learn through a wide variety of different mechanisms, including lectures, reading assignments, homework sets, laboratory projects, video, and more recently, interactive multimedia. Many educational researchers [5, 8, 12] have studied which of these different mechanisms are best suited to particular students' learning styles. Of all these mechanisms, the most effective are often those which involve hands-on experience [7]. However there are many experiences that are too hazardous, too costly, or otherwise impractical to deliver to large numbers of students. This situation has led to the development of an increasing number of educational simulators designed to provide students with experience in the safety, comfort, and convenience of their university computing laboratories [4, 6, 9, 10, 11].

Virtual reality, VR, is a rapidly emerging computer interface that offers potential to increase the impact and effectiveness of these educational simulators. The main goal of VR is to completely immerse the user within the simulation, and to make him or her believe that they are physically inside the computer generated environment. Just as different methods of instruction are more or less effective for different students, VR will have certain applications for which it is most effective. In order to determine just exactly what those particular applications are, as well as learning the capabilities of this new technology and how best to apply it to educational tasks, a series of prototype VR based educational simulations are currently under development in the Chemical Engineering department at the University of Michigan [1-3]. This paper presents the initial student evaluations of one of those prototype applications, designed to aid students in evaluating the hazards and safety systems present in a modern chemical production facility. This application was chosen because insight and the ability to clearly visualize the equipment and its surroundings are critical to an effective hazards analysis, and because it reflects an environment to which students would not normally have easy access, particularly when conditions are unsafe.

THE MODEL

The chemical facility being modeled is a pilot plant operation for the production of polyether polyols from ethylene oxide, propylene oxide, glycerin, glucose, and other materials. The major pieces of equipment present are one stirred tank reactor and two post-reaction processing vessels. Also present in the pilot plant are various pumps, filters, scrubbers, and process monitoring equipment. Safety features include a sprinkler system, fire extinguishers, pressure relief systems, concrete walls, blowout panels, emergency shower / eyewash stations, and explosion proof electrical connections.

The neighborhood surrounding the plant is included in the model, showing the relationship of the various chemical production facilities and storage tanks to the surrounding environment. Some concerns present in the neighborhood include local businesses, a hospital, and a river that provides drinking water for a nearby city. The initial viewpoint upon starting the simulation is from an aerial perspective, showing students the big picture before moving in to look at the details.

A help system built into the model provides additional information regarding each of the buildings and objects present. Information not specifically related to any particular object is also available, such as reaction chemistry and material safety data sheets (MSDS) for each of the chemicals involved. The help system is implemented in a separate window within the MS Windows environment, and includes both text and scanned photographs interconnected in a hypertext format. Eight rolls of pictures taken at the chemical plant show students what the equipment looks like in the real world, and are also used for applying realistic textures to objects within the model. Students activate the help system by clicking on an object with the mouse, or by typing "H" or "?" from the keyboard. The former method opens up the help page related to the object chosen, whereas the latter presents the table of contents for the help system.

Users navigate through the model using a joystick. Our experience has shown this to be the most effective method for experienced users, however it does present difficulties for those not accustomed to using joysticks. A head mounted display unit (HMD) is supported by the simulation, and was available for student use, but is not required. A head tracker built into the HMD aids in navigation.

THE STUDENTS

The students involved were all enrolled in a senior plant design course that included two weeks coverage of safety related material. The second of these weeks was specifically on hazards analysis. Students were selected for one of three categories based upon the last digit of their student number. Students with even student numbers were asked to perform the safety analysis from the written description only, and to evaluate the VR simulation after their safety analysis was complete. Students with odd student numbers were asked to use both the written description and the simulation to perform their safety analysis. In addition, students whose student numbers ended in eight were given the opportunity to tour the chemical plant upon which the simulation was based, and to discuss the facility with the production personnel present. There were 15 students who fell into this latter category, ten of which were able to take advantage of the opportunity and five of which were unable to do so due to scheduling conflicts. Two of the students in the class were actively involved in the development of the model, including the student who performed most of the day to day model construction.

PRELIMINARY RESULTS

Along with their safety analysis, each student was asked to fill out an evaluation form regarding the simulation. These evaluations do not have names on them and were not considered in determining students' grades. They do however have reference numbers which will allow us to correlate student responses to performance on the safety analyses. For the purposes of assigning homework grades it was not considered fair to judge the quality of the analyses, since different students had access to different amounts of information when performing their analyses. Therefore the homework grades were based upon the apparent amount of effort and thought shown by each student, rather than by the validity of their conclusions. An in-depth review of the students' analyses will be performed as time permits.

The evaluation forms had three sections, for background information, rankings, and short answers. Within the ranking section students were asked to evaluate various components of the model on a scale from 1 (low, worst) to 5 (high, best). Figure 1 shows how students evaluated the overall value of the simulation, both as it stands now and the potential value when the project is completed and refined. Most of the students rate the current value as medium to low, with 79% of respondents giving a ranking of 2 or 3. However 82% of the class sees the potential value as 4 or 5 once the model is completed. Figure 2 shows the ranked value of the help system, again for both the current implementation and when completed. Similarly to the overall simulation rankings, 81% of the students give the current help system a ranking of 3 or below, whereas 76% rank the potential value at 4 or 5.

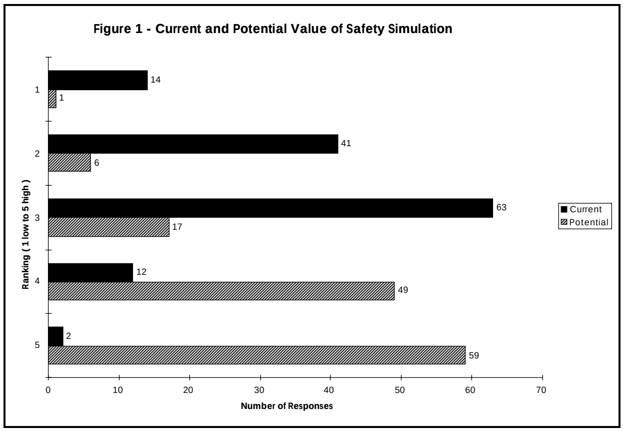


Figure 1 - Current and Potential Value of Safety Simulation

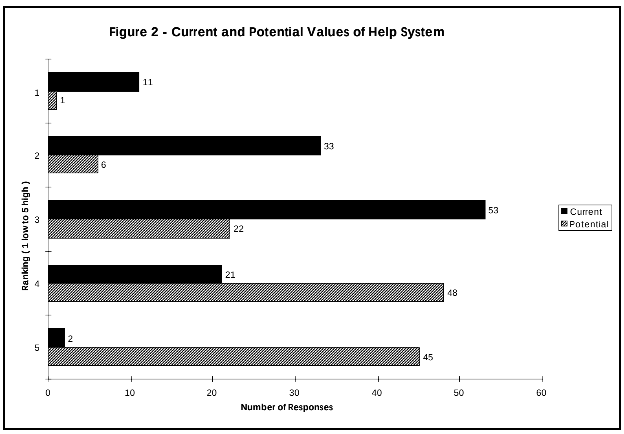


Figure 2 - Current and Potential Values of Help System

The next set of questions deals with the current and potential benefits of using the head mounted display as opposed to viewing the simulation on the regular screen. This is an issue that has serious trade offs to consider. The use of the HMD produces a much more immersive simulation, completely surrounding the user and thereby adding greatly to the believability and impact of the experience. This high degree of immersion is the central goal and focal point of virtual reality as opposed to other forms of simulation. In addition the head tracker provides the user with a more natural means of adjusting their viewpoint than with the joystick alone. The main drawback to using the HMD is that the resolution available today for reasonably priced HMDs is still very poor compared to current monitor standards. Most low-cost HMDs use NTSC television signals (based upon camcorder viewfinder technology) which have 512 scan lines. This signal must be produced by converting the nearest standard computer resolution of 480 lines, which is lower than today's more common computer resolution of 600 or 768 scan lines. The net result is that it is nearly impossible to read anything in the HMDs used for this project unless the text is very large in the virtual world, such as a STOP sign. Students using the HMDs were forced to peek under the edge of the glasses to see the help system displayed on the ordinary monitor. The increasing popularity of virtual reality holds promise, however, that true VGA resolution HMD devices will become available at reasonable prices within the next year. Student rankings of the value of the HMD follow the same trends as the previous two categories, with 83% of the students giving the current HMD technology a ranking of 3 or below and 80% ranking the potential benefits at 4 or 5, as shown in Figure 3.

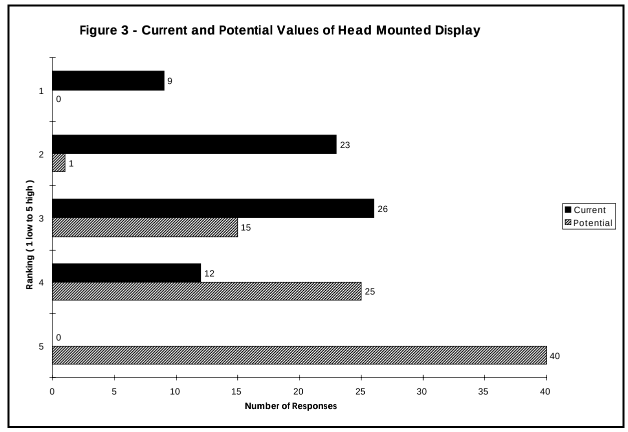
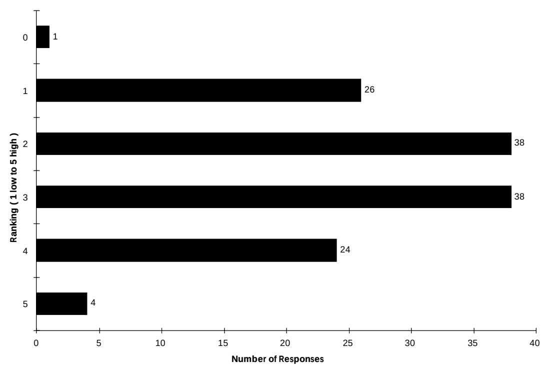


Figure 3 - Current and Potential Values of Head Mounted Display

A final question in the ranking section of the questionnaire asked students how much their understanding of the process and its hazards had increased as a result of running the simulation. The result was a near perfect bell curve centered between 2 and 3, as shown in Figure 4. Note that one student gave a value of zero on a scale from 1 to 5. This wide range of responses indicates that certain students will benefit strongly from the highly visual representation that virtual reality offers, and others will gain little beyond the written description. (Of course this also depends on how much each student was able to gather from the written materials.) Although learning styles were not specifically addressed in this study, it is expected that those students answering 4 or 5 to this question are highly visual learners, whereas those answering 2 or below are more verbally oriented. (At this point there was little if any information in the simulation that was not also present in the written description.)

Figure 4 - Increased Understanding as a Result of the Simulation



The short answer portion of the student evaluations provided a wide variety of suggestions and other valuable feedback for the program developers. The most commonly voiced complaint was difficulty in navigation. Many users found themselves underground or with other equally undesirable viewpoints, and were unable to return to a normal status without restarting the program. (The simulation has a “reset view” key, but apparently none of the students were aware of its existence.) There are some steps that can and will be implemented to minimize these difficulties. However some of the problems are a matter of personal preference and will require further consideration before appropriate changes can be made. Examples of the latter category are whether or not users should be able to walk through walls and whether or not users are allowed to fly. Reducing these capabilities constrains the viewpoint to a more normal range, but makes it more difficult to enter buildings and to see the overall layout respectively.

Comparisons between the two groups of students (those running the simulation before performing their safety analysis and those running it afterwards) do not show any significant variations in their evaluations of the model, the equipment, the help system, or their future potential. Neither has any difference been noted so far in the amount of apparent effort that the students put into the assignment. It is hoped that a careful review of the students' safety analyses will reveal greater insight and depth from the reports produced with the benefit of the virtual reality based simulation, but that review has not yet been completed.

CONCLUSIONS

The simulation as it stands now is incomplete, and as such does not provide major benefits beyond the written description of the chemical production facilities. This conclusion reached by the student evaluators is valid, in that the simulation has only been under development for a few months, primarily by a single student who was carrying a full-time load in addition to working on this project voluntarily. On the other hand, 20% of the class reported that they increased their understanding of the chemical production process and its associated hazards significantly as a result of running the simulation, and over 80% of the class predict that the simulation will have a high value once the model and help system are completed and refined and once the technology improves.

Beyond the incompleteness of the current model and help system, the most significant weakness reported is difficulty with users’ navigation. The frequency of this complaint reflects a need for increased attention to the human-computer interface, and for improvements in the documentation and instructions. In particular, the instructions for the operation of the joystick need to be visual in nature rather than text based. Virtual reality is a very visual experience, designed to appeal to visual learners. It is not appropriate for the operating instructions to consist of several pages of printed text. It became apparent that many students were not reading the instructions when they requested that certain features be added to the program which were in fact already present (e.g., "reset view"). Increased user familiarity with joysticks and perhaps the purchase of higher quality joysticks will also improve this situation.

Many suggestions have been gathered regarding potential improvements to the program. These suggestions will be evaluated and implemented as appropriate. Further analysis of the students' reports will be conducted in the near future, and further testing with additional groups will also be performed.

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AUTHOR INFORMATION

John T. Bell

John T. Bell, Lecturer in the Chemical Engineering Department at The University of Michigan (3074 H.H. Dow, Ann Arbor, MI 48109-2136, (313) 763-4814, JohnBell@umich.edu), received his BS in Chemical Engineering in 1984 from Georgia Institute of Technology, under the cooperative education program. He then did a year of graduate study at l'Institut du Génie Chimique, in Toulouse France, where he received a Diplôme des Études Approfondes, before moving on to the University of Wisconsin, Madison, where he received a MS in Chemical Engineering in 1987, a MS in Computer Science in 1988, and a Ph.D. in Chemical Engineering in 1990. Before coming to the University of Michigan, John spent four years teaching advanced computer courses at The Computer Classroom, Inc., a private computer training firm in Madison, Wisconsin. While at Michigan John has taught plant design, chemical kinetics and reactor design, and unit operations laboratory courses, and has tutored selected students in C Programming and virtual reality programming techniques.

H. Scott Fogler

H. Scott Fogler, Vennema Professor of Chemical Engineering at The University of Michigan (3074 H.H. Dow, Ann Arbor, MI 48109-2136, (313) 763-1361, H.Scott.Fogler@umich.edu), has over 130 research publications. In addition, he is author of three books, including the second edition of "The Elements of Chemical Reaction Engineering", which is the most used book on this subject in the world, and his most recent book “Strategies for Creative Problem Solving.”

In 1980, Professor Fogler was a first recipient of the newly instituted award for Outstanding Research from the University of Michigan College of Engineering, and also in 1980, received the Chemical Engineer of the Year Award from the Detroit section of the American Institute of Chemical Engineers. In 1987, he received the University of Colorado Distinguished Alumnus Award, and in 1988, he was elected President of the Computer Aids for Chemical Engineering (CACHE) Corporation. More recently, Scott was awarded 1995 recipient of the Warren K. Lewis award of the American Institute of Chemical Engineers for contributions to chemical engineering education.