

## **Virtual Laboratory Accidents Designed to Increase Safety Awareness**

**John T. Bell, H. Scott Fogler**  
**Department of Chemical Engineering**  
**University of Michigan, Ann Arbor, MI 48109-2136**

### **Summary**

Safety rules are often disregarded in undergraduate laboratories, due to either forgetfulness or complacency. People remember experiencing ( near ) accidents much longer and more vividly than written rules; however it is unacceptable to deliberately cause accidents just to emphasize the importance of safe lab practices. It is therefore proposed to develop a series of virtual reality based laboratory accidents, that will provide valuable learning experiences in the relative safety of computer labs and dormitories. This paper describes preliminary steps taken in this new project, and outlines future plans.

### **Background**

Laboratory safety is extremely important, particularly in undergraduate laboratories where students first develop practices and habits that they may carry with them throughout their careers<sup>1-3</sup>. Because this importance is widely agreed upon, all undergraduate chemistry and unit operations labs include some amount of safety training, encompassing at a minimum a long list of safety rules<sup>4</sup>. These rules are often handed out on the first day of lab, along with the course grading policy, exam schedule, and instructor's e-mail and office location.

In spite of these precautions, however, accidents, near misses, and rule violations continue to occur. Two major causes for these continuing safety violations are forgetfulness and complacency, the latter of which can be considered as forgetfulness of the importance and significance of the rules, as opposed to forgetfulness of the rules themselves. The bottom line is that safe practices are not retained in students' memory as well as we all would like.

Those persons who have ever been involved in an accident, however, tend to remember their experience much longer and more vividly than any set of written rules. As a result, they tend to follow safe practice guidelines much more rigorously, in order to ensure that such experiences never happen again. One conclusion would be that if we could involve all of our students in lab accidents, then they would all follow safer lab practices in the future. Obviously, this is not an acceptable solution!

Virtual reality, ( VR ), on the other hand, strives to deliver highly realistic experiences through the medium of enhanced computer simulations<sup>5</sup>. The ultimate goal of virtual reality is to produce simulations so realistic and believable that users cannot discern them from reality. Although that level of realism has not yet been achieved, ( and probably never will be ), some VR simulations have achieved sufficient realism to produce physiological fear responses in patients undergoing phobia treatment<sup>6</sup>. VR simulations are enhanced through high-speed

interactive immersive three-dimensional computer graphics, audio spatialization, tactile and force feedback, cognitive and psychological effects, and special equipment such as head-mounted displays ( HMDs ). One recently developed tool in VR is VRML, the Virtual Reality Modeling Language, which allows three-dimensional interactive computer graphics to be easily distributed and displayed using an ordinary web browser ( and plug-in )<sup>7</sup>. Although VRML does not have the same impact as full-blown VR, it does have the advantage of near instantaneous access to a nationwide ( and worldwide ) audience.

## Previous Work

Previous efforts to apply VR to engineering education have produced three major and six minor modules on three different computer platforms, for a total of 27 different versions<sup>8-17</sup>. All of the minor modules and one of the major modules are currently available for free download from the world wide web, and the remaining modules will be ready soon<sup>18</sup>. All modules support but do not require special VR equipment, such as head-mounted display systems, the Fakespace BOOM, or a CAVE.

The most significant major module, Vicher1, illustrates mechanisms of heterogeneous catalytic reactions, and industrial responses to three different types of catalyst decay. Vicher1 includes three reaction engineering areas where students can operate and explore virtual reaction equipment, three microscopic environments where students observe catalytic reaction mechanisms at the molecular level, and a welcome center for navigational and human-factors purposes. Vicher1 also includes an HTML-based help system designed to provide additional information at a level of detail not practical in student-affordable VR.

Vicher2 is very similar to Vicher1, and provides experiences relevant to non-isothermal chemical reaction engineering in three virtual reactor areas and a welcome center. Vicher2 also has a help system similar to that developed for Vicher1. The third major module, currently named "Safety", allows students to explore a virtual polyether polyol pilot plant in order to perform a safety and hazards analysis. Preliminary studies found that unguided and unstructured exploration was not as educationally effective as was hoped, and so this module is now being augmented with an interactive question-and-answer system in order to provide better direction and incentive for exploration.

The minor modules were developed to test and illustrate specific techniques for the application of VR to the delivery of scientific information on student-affordable personal computers. Topics covered in the minor modules include thermodynamic relationships, fluid flow, crystal structures, and the visualization of azeotropic residue curves in four-component space.

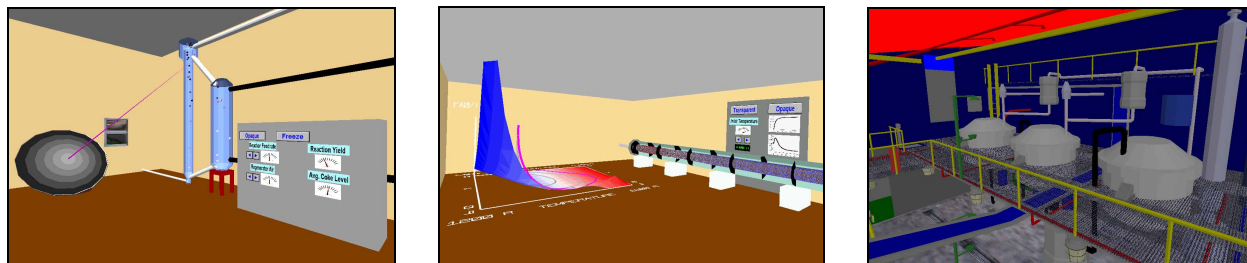


Figure 1: Transport Reactor Room from Vicher 1, Staged Reactor Area from Vicher 2, and a Sample Image from Safety.

## The New Project

The general goal of this project is to produce a series of VR-based laboratory accidents that will allow students to experience first-hand the importance and potential consequences of laboratory safety. A preliminary set of safety rules has been selected as shown in Table 1, based upon criteria of relevance to a wide range of lab situations, potential consequences, and adaptability to a VR environment. For each of these rules it is intended to develop two versions of an accident simulation – One in which the user disobeys the rule and suffers the consequences, and one in which the user obeys the rule and is saved as a result. It is intended to produce these simulations in both VRML format for experiencing online, and binary executable format for download and execution separate from the web browser. The latter format will only run on certain computer platforms, but will provide support for special equipment and effects not possible in VRML. At the time of this writing, first drafts of some of the VRML applications have been completed, as indicated in Table 1, and work is commencing to port these initial drafts to binary executable format. One of the reasons for undertaking that conversion now is to ascertain exactly what steps need to be taken, to determine what special issues must be considered when developing the simulations, and to develop a framework for future development.

<u>Rule</u>	<u>Status</u> <sup>†</sup>
1. Always Wear Safety Glasses in the Laboratory	VRML “obey” and “disobey” done.
2. No Food or Drink Allowed in the Laboratory	VRML “disobey” done.
3. Keep Aisleways Clear at All Times	VRML “obey” and “disobey” done.
4. No Sandals or Tennis Shoes Allowed in Lab.	
5. Secure Long Hair and Loose Clothing	
6. Know Locations of Showers, Exit, etc.	
7. Securely Fasten Compressed Gas Cylinders	
8. No Horseplay Allowed in Lab	
9. Store and Segregate Chemicals Properly	
10. Safety Inspection of a Pilot Plant	Previously developed. ( See above. ) This simulation will be included here to maximize impact of both projects.

Table 1: Some Currently Planned Safety Rules and Simulation Status

On the web site, the simulations will be grouped into a table, such as that shown in Figure 2, that will provide links for both versions of VRML simulation and several formats of executable programs for download. Links from the "safety rule" column of the table will provide detailed descriptions and information regarding each rule. Additional web pages will round out the project by providing additional safety related information, bibliographic references, and links to external safety related web sites.

---

<sup>†</sup> The modules marked “done” have their first draft completed. All modules need polishing and refining.

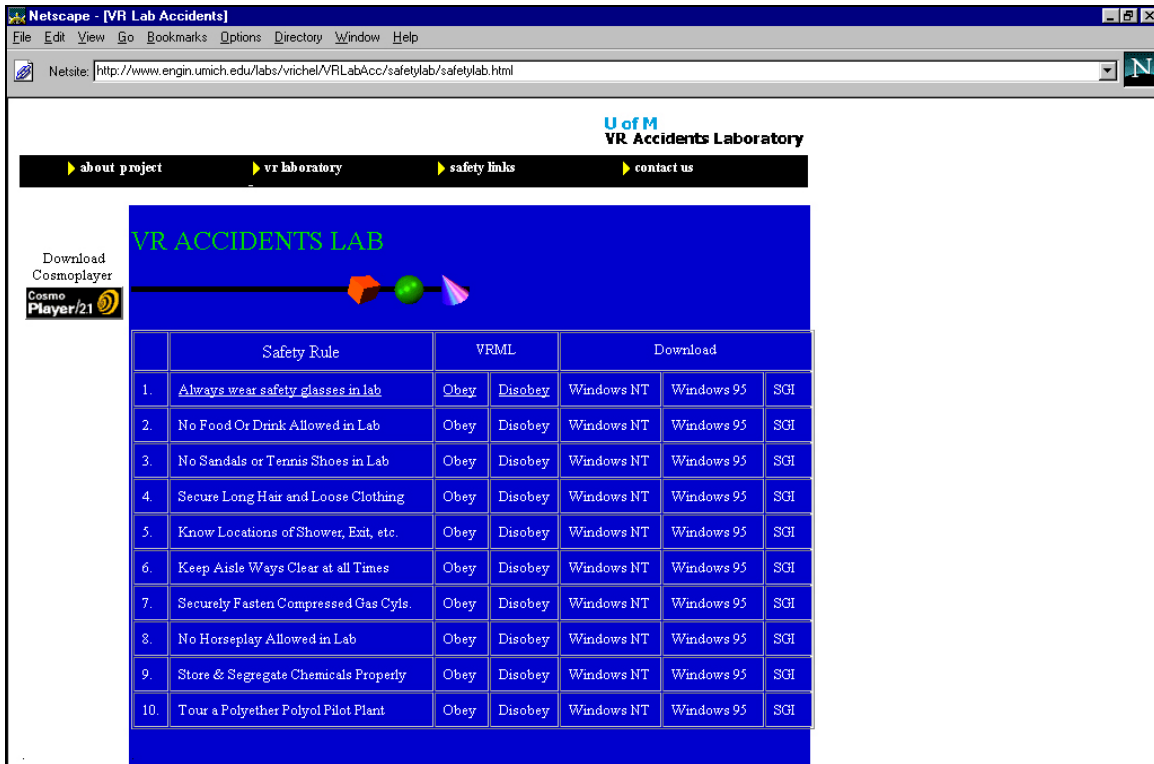


Figure 2: Sample Table For Accessing Accident Simulations

### Safety Rule 1: Always Wear Safety Glasses in The Laboratory

Figure 3 shows an early scene from the VRML model dealing with safety glasses. In this case, the user has elected to wear their glasses, as evidenced by the frames visible at the edges of the view. An experiment in progress can be seen just to the right of center, involving two flasks and a gas cylinder connected with flexible tubing. As the user approaches the experiment, a hose breaks loose and sprays the user, driven by pressure from the compressed gas cylinder. Fortunately for this particular user, their safety glasses saved them from serious injury, as shown in Figure 4. In the alternative case, the screen fades to black as the user permanently loses their eyesight.

### Safety Rule 2: No Food or Drink Allowed in the Laboratory

The second scenario under development deals with the prohibition of food and drink in the laboratory. In this scenario there is a soda can sitting on the lab bench, immediately below a leaking hose, as shown in Figure 5. ( The leak may not be readily apparent to all users, but that only goes to emphasize the significance of unseen hazards. )

If the user has chosen to disobey the safety rule, then a hand appears and brings the soda can to the user's face, as shown in Figures 6 and 7. At this point the user's vision blurs, and their viewpoint spirals down to a face-up view of the ceiling and the bottom of the benches before fading to black. For the "obey" option, ( not yet written ), the hand will pick up the soda and throw it in the trash, causing a small trash fire or explosion, with a message to the effect of "Aren't you glad you didn't drink that?"

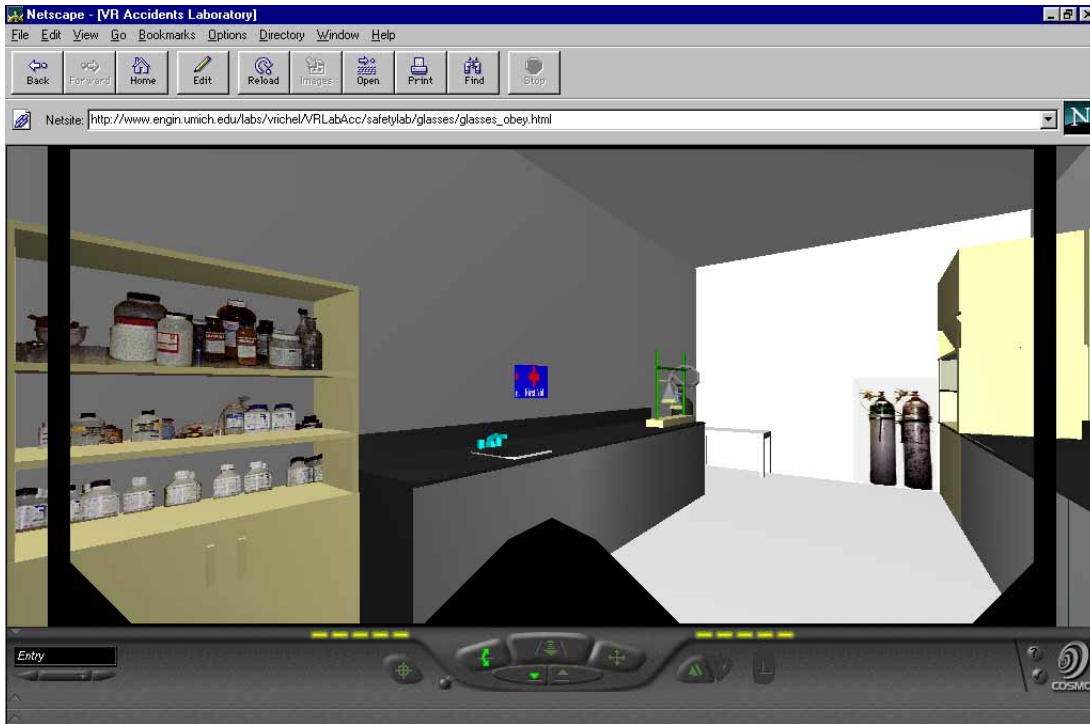


Figure 3: An Early View Inside A Virtual Chemistry Lab



Figure 4: Virtual Safety Glasses Saved This User From Serious Injury

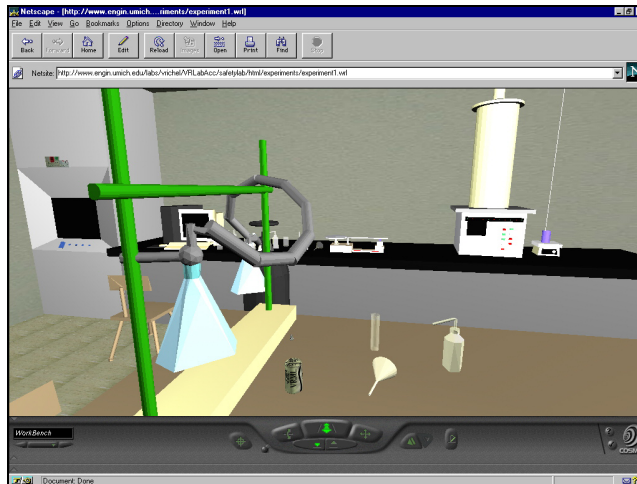


Figure 5: Chemicals Leaking into a Soda Can

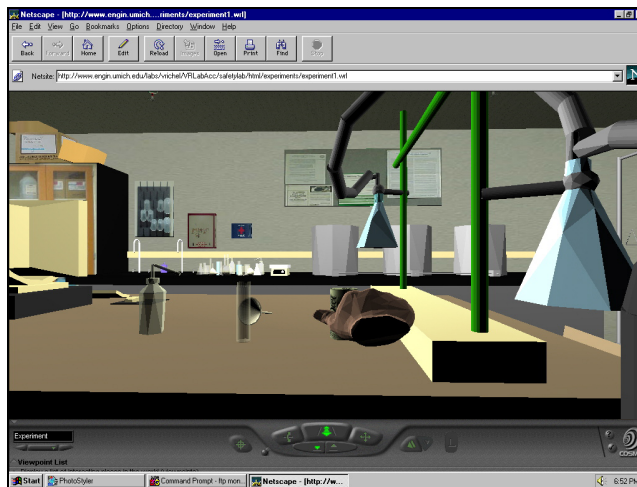


Figure 6: User Reaching to Take a Drink

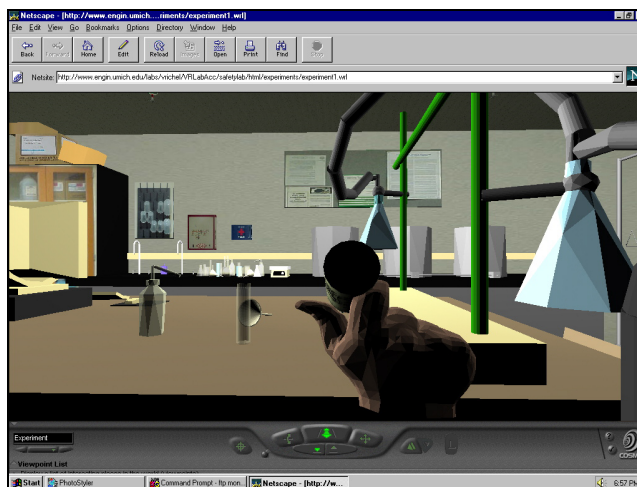


Figure 7: Here Comes Trouble



One possibility considered when this scenario was first developed was to deliberately induce simulator sickness after the user drank the soda. Simulator sickness is a form of motion sickness that sometimes occurs in VR simulations due to inconsistencies between visual motion queues provided by the simulation and the inner ear's sense of balance. As far as this author is aware, all previous studies of simulator sickness have centered around understanding and eliminating the phenomena, so this would be the first known application to deliberately *use* simulator sickness to enhance the impact of the simulation.

### **Safety Rule 3: Always Keep Aisleways Clear**

Under this scenario, the user mixes two chemicals, which react violently to produce a small fire and lots of ( hazardous ) smoke, as shown in Figure 8. The user then has about 10 seconds to evacuate the lab safely, which is possible if the aisleways are clear ( “obey” ), but not possible otherwise ( “disobey” ). It should be noted that this scenario is based in part on a real industrial accident, in which one worker was burned much more severely than another due, in part, to the difference in their speed of evacuation from the laboratory. A full discussion of the industrial accident, and a link to a relevant web site<sup>19</sup> will be included in the supplemental materials for this scenario.

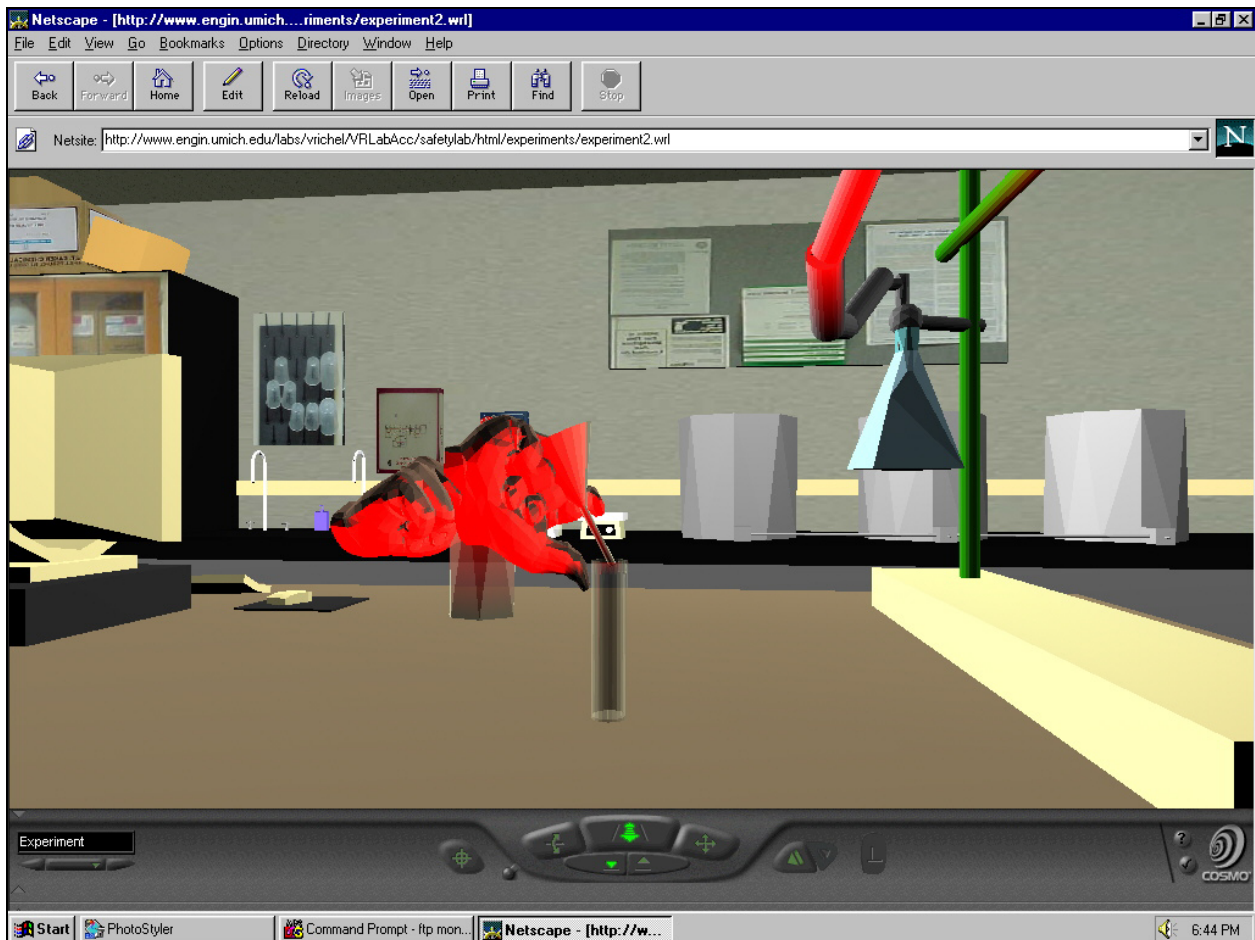


Figure 8, Explosive Reaction in the “Keep Aisleways Clear” Scenario.

One of the big human-factors challenges in developing this scenario is ensuring that users can distinguish the increased navigational difficulty caused by the cluttered aiseways. The reason that this is a challenge is that many users have difficulty navigating through **any** virtual world, and so the increased difficulty caused by the clutter may not be readily apparent.

## The Timeline

This project was originally conceived during the summer of 1998. At that time the initial web frame structure was assembled and the first draft of the first VRML simulations ( regarding safety glasses ) were developed. During the fall of 1998, a group of four students developed two new VRML simulations ( forbidding food and drink and requiring clear aisle ways in the lab ) as part of a virtual reality class project. A proposal was also submitted to the National Science Foundation ( under the Course, Curriculum, and Laboratory Improvement program of the Division of Undergraduate Education ) during that time, in order to continue this work as a funded project. Current activities ( winter 1999 ) involve the integration of existing components into a cohesive whole, and the conversion of one or more of the VRML programs into binary executable format. Work is also progressing to develop a set of tools, techniques, examples, and overall infrastructure to guide future student effort. Long term plans call for a three year development schedule, culminating in a CD ROM to be distributed through the SACHE ( Safety and Chemical Engineering Education ) organization<sup>20</sup>, and a web site to be freely accessible by all interested parties, assuming adequate funding.

## Acknowledgements

The authors would like to express their appreciation to the University of Michigan students Sharon Ohba, Michael Cataletto, Rob King, Tim Mygatt, and Michelle Westbrook who have contributed time and effort to this project, and to the following parties who have offered support in the form of technical and other assistance: Joe Louvar, SACHE chair and Director of Analytical Chemistry of Chemical Engineering for BASF Corporation, Dan Crawl, H.H. Dow Professor for Chemical Process Safety at Michigan Technological University, John Jechura, Senior Engineer for Refining Technology at Marathon Oil Company, and Lisa Stowe, Certified Industrial Hygienist at the University of Michigan Department of Occupational Safety and Environmental Health. Previous projects of the VRiChEL Lab have been funded by the National Science Foundation. A complete list of all students who have worked on VRiChEL projects is available on the VRiChEL web site<sup>18</sup>.

## Bibliographic Information

1. Young, Jay A. "How 'Safe' Are the Students in My Lab?", *Journal of Chemical Education*, **60**(12), pp 1067-68, December 1983.
2. Dombrowski, JoAnne Morgan, and Ray R. Hagelberg, "The Effects of a Safety Unit on Student Safety Knowledge and Behavior", *Science Education*, **69**(4), pp 527-33, July 1985.
3. Kavarian, H.R., "Safety Management in Engineering Laboratories", *Professional Safety*, **34**(7), pp 27-30, July 1989.
4. Department of Occupational Safety and Environmental Health, "Laboratory Safety: Practices for Progress", University of Michigan, Ann Arbor, MI 48109, 1990.
5. Pimental, Ken and Teixeira, Kevin, "Virtual Reality : Through the New Looking Glass", second edition, Windcrest Books, 1995.



6. Grady, Sean M., "Virtual Reality, Computers Mimic The Physical World", Facts on File, Inc., New York, NY, 1998, p93.
7. Carey, Rikk, and Gavin Bell, "The Annotated VRML 2.0 Reference Manual", Addison Wesley, 1997.
8. Bell, John T., and H. Scott Fogler, "Vicher: A Prototype Virtual Reality Based Educational Module for Chemical Reaction Engineering", *Computer Applications in Engineering Education*, 4(4), October, 1996.
9. The Virtual Reality in Chemical Engineering Laboratory Web Site, <http://www.engin.umich.edu/labs/vrichel>
10. Bell, John T., "Virtual Reality in The Chemical Engineering Classroom", *Proceedings of the American Society for Engineering Education Annual Conference*, Seattle, WA, June 1998.
11. Bell, John T. and H. Scott Fogler, "The Application of Virtual Reality to Chemical Engineering and Education", *Proceedings of the American Institute of Chemical Engineers Annual Meeting*, 1998, Paper number 170F.
12. Bell, John T., and H. Scott Fogler, "Virtual Reality in Chemical Engineering Education", *Proceedings of the 1998 North Central Sectional ASEE Conference*, April 3-4, 1995, University of Detroit Mercy, Detroit, Michigan, ( Best Paper Award. )
13. Bell, John T., and H. Scott Fogler, "Ten Steps to Developing Virtual Reality Applications for Engineering Education", *Proceedings of the American Society for Engineering Education Annual Conference*, Milwaukee, WI, June 1997.
14. Bell, John T., and H. Scott Fogler, "Undergraduate Research Experiences Developing Virtual Reality Based Educational Modules", *Proceedings of the American Society for Engineering Education Annual Conference*, Milwaukee, WI, June 1997.
15. Bell, John T. and H. Scott Fogler, "The Application Of Virtual Reality to Chemical Engineering Education", *Proceedings of the 1997 International Conference on Simulation in Engineering Education*, Society for Computer Simulation, San Diego, CA, 1997.
16. Bell, John T., and H. Scott Fogler, "The Status and Prospects of Virtual Reality in Chemical Engineering", Presented at the *Annual Meeting of the American Institute of Chemical Engineers*, Chicago, IL, November 1996. Copies available from the author upon request.
17. Bell, John T., and H. Scott Fogler, "Recent Developments in Virtual Reality Based Education", *Proceedings of the American Society for Engineering Education Annual Conference*, Washington, DC, June 1996.
18. The Virtual Reality in Chemical Engineering Laboratory Web Site, <http://www.engin.umich.edu/labs/vrichel>
19. John Jechura's Burn Page, <http://www.webspesso.com/john's.htm>
20. Safety and Chemical Engineering Education, a program of the Center for Chemical Process Safety Division of the American Institute of Chemical Engineers, <http://www.aiche.org/docs/ccps/sachece.htm>

## Biographical Information

### JOHN T. BELL

( Lecturer, Department of Chemical Engineering, University of Michigan, 2300 Hayward Room 3074, Ann Arbor, MI 48109-2136, ( 734 ) 763-4814, [JohnBell@umich.edu](mailto:JohnBell@umich.edu), <http://www.engin.umich.edu/dept/cheme/bell.html> ) John holds a MS in computer science and a PhD in chemical engineering. His research interests involve the application of emerging computer technologies ( e.g. virtual reality ) to chemical engineering and education.

### SCOTT FOGLER

( Vennema Professor of Chemical Engineering, same address, ( 734 ) 763-1361, [H.Scott.Fogler@umich.edu](mailto:H.Scott.Fogler@umich.edu), <http://www.engin.umich.edu/dept/cheme/fogler.html> ) Scott has over 140 research publications, including "The Elements of Chemical Reaction Engineering" ( the most used book on this subject in the world ) and "Strategies for Creative Problem Solving." He was the 1995 AIChE Warren K. Lewis award recipient for contributions to chemical engineering education.