

## **Recent Developments in Virtual Reality Based Education**

**John T. Bell, H. Scott Fogler**  
**University of Michigan**

### **ABSTRACT**

A series of virtual reality based educational modules are being developed to explore the capabilities of this emerging technology, and to determine how and where virtual reality can provide the greatest benefits to engineering educators. The most advanced application, Vicher, has been significantly expanded and split into two modules. Student evaluations of a newly developed safety analysis module show great promise, but also the need for further development. Other modules being developed cover topics in atomic crystal structures, fluid flow characteristics, thermodynamic relationships, and four component azeotropic distillation. This paper will describe the latest developments in the ongoing investigation of virtual reality as an educational medium.

### **INTRODUCTION AND BACKGROUND**

Engineering educators are making use of an increasing number of computer simulation packages to aid them in attaining their educational objectives<sup>5,7,9,10</sup>. The reasons for doing so include the desire to reach students that have alternate learning styles<sup>4,11</sup>, to provide experience based education<sup>6</sup>, and to augment traditional laboratory facilities that are being stretched increasingly thin with growing enrollments<sup>3</sup>. Computer simulations also provide students with access to environments that would not otherwise be available to them.

Virtual reality, VR, is an emerging technology that strives to greatly increase the realism of simulations by immersing users deeply within interactive three dimensional computer generated environments. This added realism has great potential to increase the impact and overall effectiveness of educational simulations. VR may also bring previously unconsidered capabilities to engineering education.

However before VR can be effectively applied, it is first necessary to determine its strengths and weaknesses, the situations that are most apt to benefit from VR, and how to employ VR in scientific and technical contexts. In order to investigate some of these issues, a number of VR based educational modules are under development, with the following three main goals:

1. To produce modules with as much practical use to as many students as possible. The educational modules all run on personal computers, and eventual distribution will involve minimal end-user cost.

2. To determine what educational situations will benefit most from virtual reality. A wide variety of topics are being explored to determine where this technology is best suited.
3. To develop techniques for the display of, and interaction with, scientific and technological information and concepts in a virtual world. These techniques can later be applied to practical engineering problems using more advanced equipment than that commonly available to students.

### RECENT DEVELOPMENTS

Along with major expansions to the original VR based educational simulator Vicher, a number of new modules have been developed to investigate different aspects of VR. Evaluations from over 150 students have been analyzed, and steps have been taken to test some modules at other universities. The following sections provide further details regarding particular modules.

#### Vicher

Vicher ( **V**irtual **C**hemical **R**eaction **M**odule ) allows students to explore various topics in chemical kinetics and reactor design. Because Vicher was first presented at this conference last year<sup>1</sup>, and because a full description of the current status of Vicher is also available<sup>2</sup>, the following covers only the changes made to Vicher over the past year.

Vicher originally consisted of a welcome center, two reaction engineering areas, and two microscopic exploration areas, as shown in Figure 1 and described previously<sup>1</sup>. Vicher has since been expanded and split into two modules, Vicher I and Vicher II, dealing with industrial response to catalyst decay and non-isothermal effects in reactor design respectively.

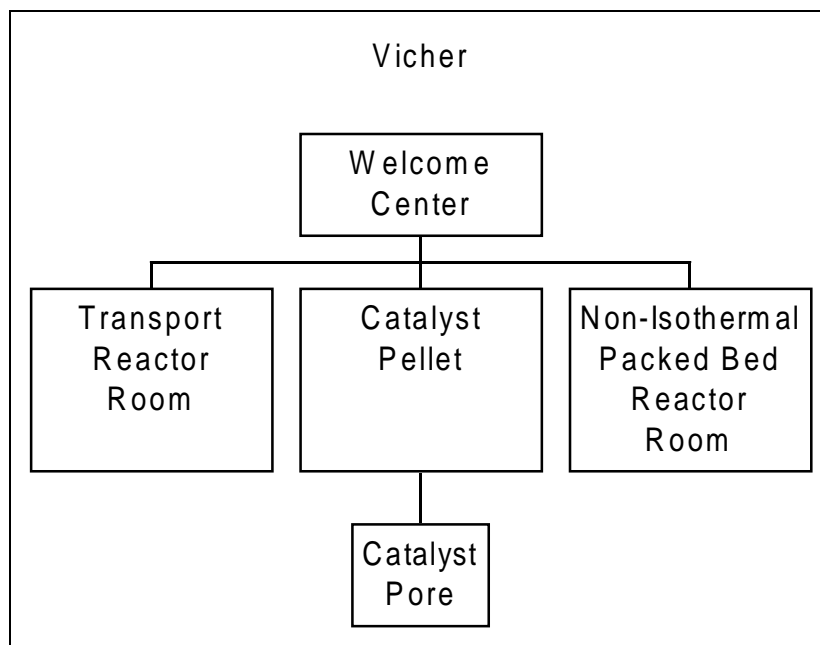


Figure 1: Original Components of Vicher

The major new additions to Vicher I, as indicated by the bold boxes in Figure 2, are a new and improved welcome center, the time-temperature reactor room, and a new close-up view of the catalyst pore surface. The time-temperature room illustrates how reactor temperatures can be increased over time to

compensate for slowly decaying catalyst, and the drawbacks involved in such a procedure. This approach is at the opposite end of the scale from the transport reactor, which is used to handle rapidly decaying catalyst. Medium rates of catalyst decay are handled by the moving bed reactor, which is currently under construction as indicated by the dashed box in Figure 2.

The catalyst pore interior has always been an area of intense activity, in which many molecules carry out diffusion and reaction processes. This high degree of activity has made it difficult for students to readily observe the reaction processes taking place. Therefore, a new area has been added to Vicher I, which shows the catalyst surface at such a high magnification factor that only a single reacting molecule is within sight at any one time. This new surface allows a single reaction to be observed repeatedly and predictably.

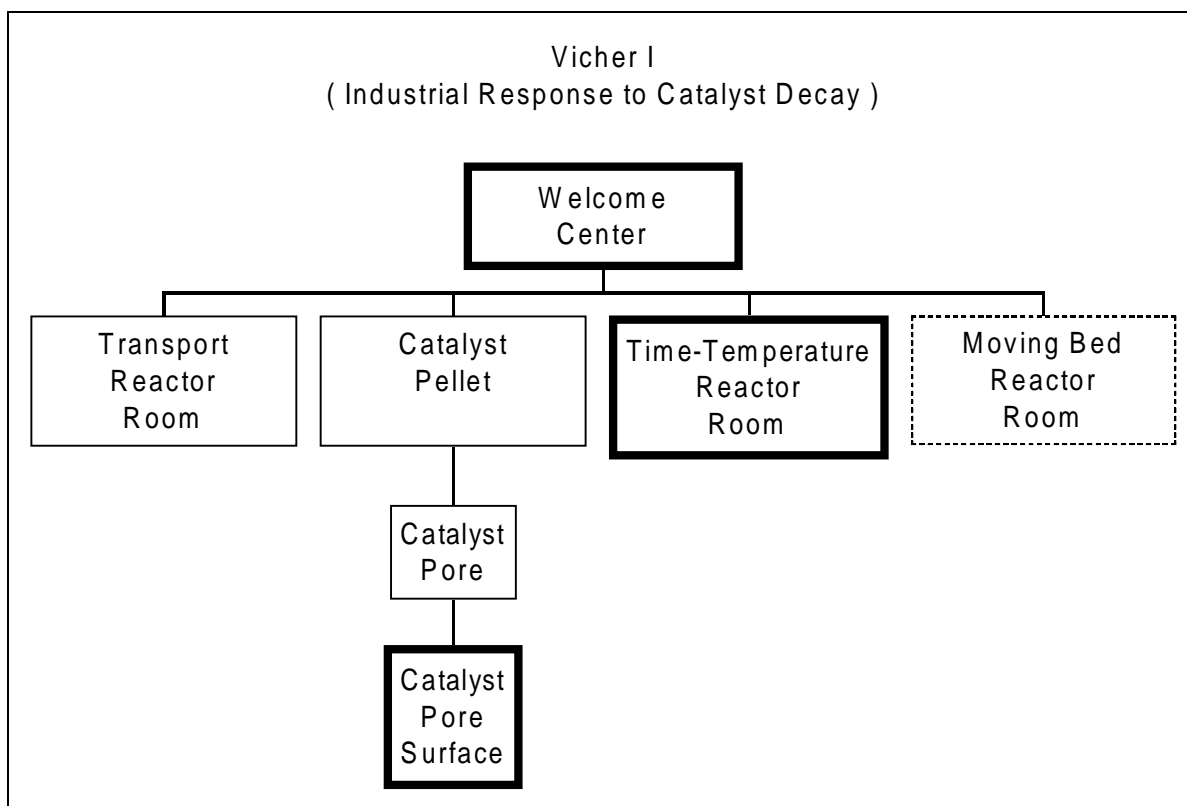


Figure 2: New Structure of Vicher I

Vicher II, as shown in Figure 3, deals with non-isothermal effects in reactor design. Newly developed areas ( bold boxes ) consist of a new welcome center and the multiple steady states reactor room. The latter area illustrates the ignition / extinction operating conditions exhibited by exothermic reactions occurring in jacketed CSTRs. Under construction ( dashed box ) is an area with multiple reactors in series with inter-stage cooling. This approach is used to overcome equilibrium limitations encountered in certain exothermic reactions. Photographs of actual equipment will be used to increase the accuracy and realism of the staged reactor area's development.

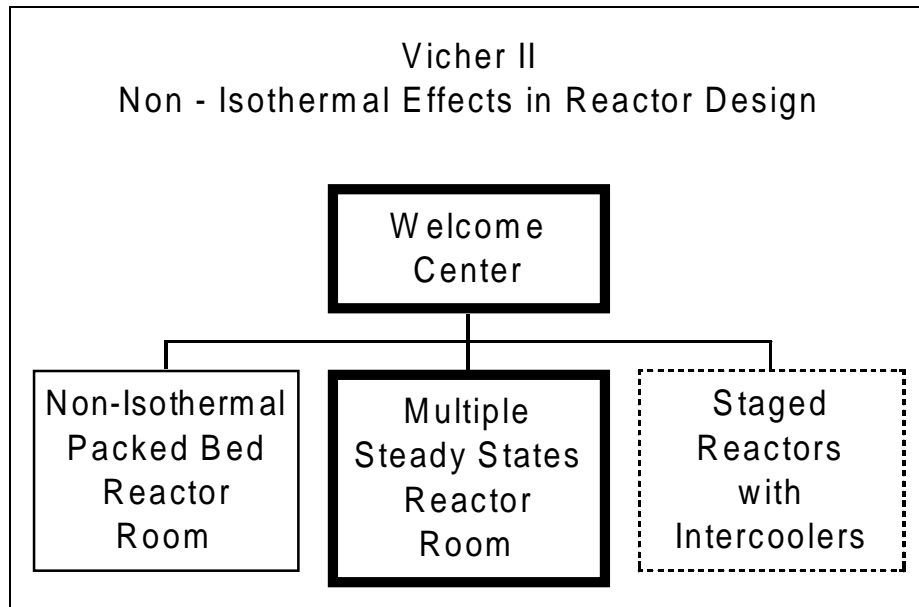


Figure 3: New Structure of Vicher II

### **Safety**

One of the strong benefits of virtual reality is that it provides unlimited access to locations that are inaccessible in the real world due to constraints of economics, logistics, physical access, or inherent danger. Focusing on the last of these constraints, danger, and to a lesser extent logistics, development has commenced on a VR module for safety and hazards analysis of a modern chemical production facility. In this module, students can not only examine the chemical processing equipment and safety systems, but they can also explore the nearby environment ( river, hospital, local businesses ) and access other safety related information such as material safety data sheets.

Eight rolls of film taken at a nearby chemical plant have been used in two ways to improve the module. First, they were used as references when constructing the virtual facilities. Second, some of the photographs were scanned into the module's "help" system, as shown in Figure 4. With this approach students can see the general layout of the equipment in virtual reality, and then pull up a separate window to see what the equipment looks like in the real world, thereby making the best use of both mediums.

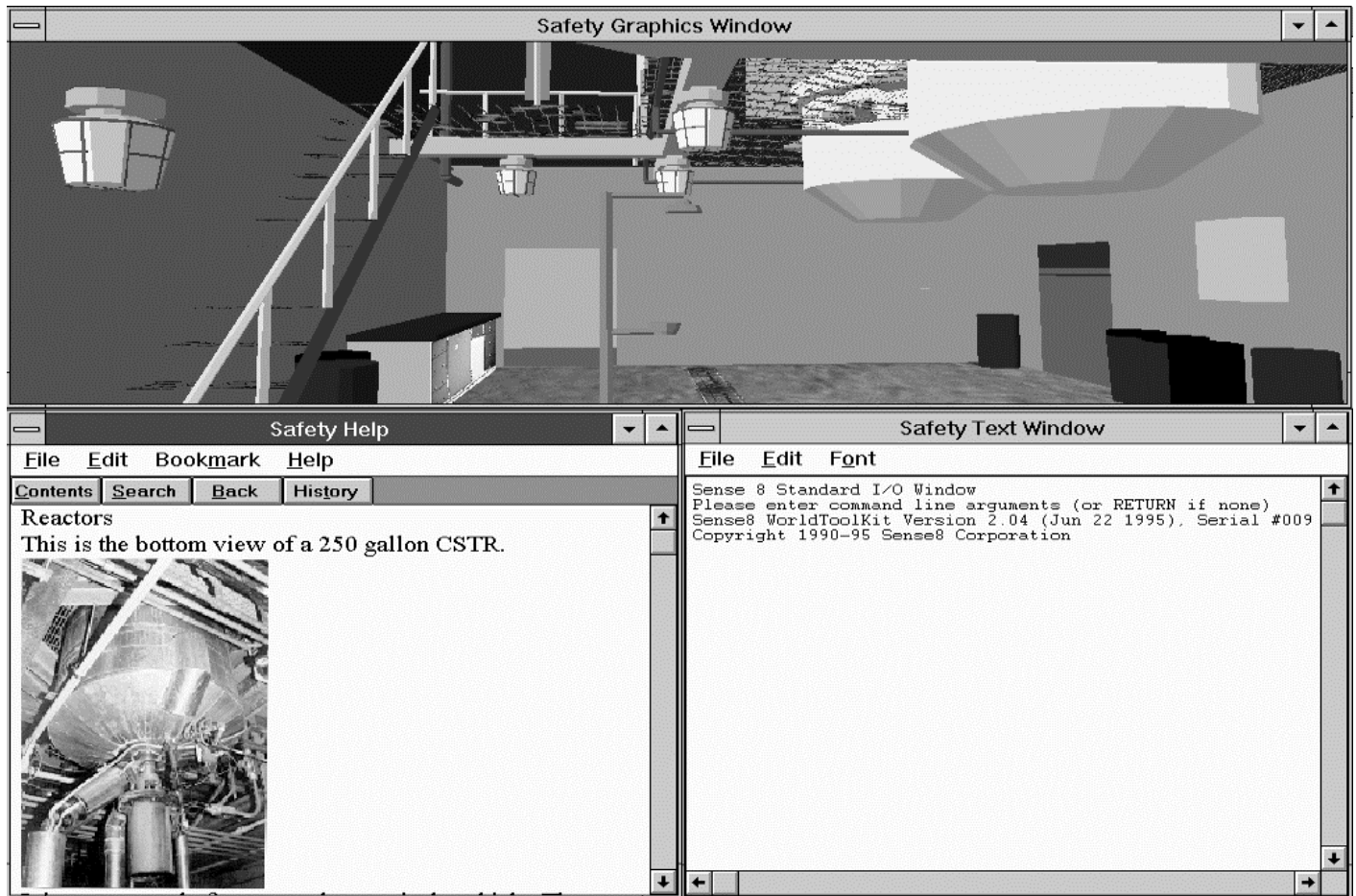


Figure 4: Inset window shows photo of actual reactor simulated in virtual reality above.

At a very early stage of development, 155 students from a first semester senior design class were asked to use the safety module to practice their hazards analysis skills, and to evaluate the current and expected value of the simulation and VR technology as educational tools. Although most students rated the current value of the simulation at medium to low, 82% see the potential value as high once the module is completed. ( The students correctly assessed that the help system was sketchy and incomplete during these early trials. There are also some navigational issues to be addressed. ) The head-mounted display employed for these trials received similar rankings, with most respondents ranking the value as medium or below with current technology and 80% ranking the value above medium for the expected value when the visual resolution improves.

### Spatial Relationships

Virtual reality provides an interactive environment in which three dimensional objects can be viewed from all possible viewpoints. The question that this raises is then "What is this capability good for? In what situations can students benefit from a three dimensional point of view?" In other fields the answer has been spatial relationships<sup>8</sup>. Architects have used VR to determine whether proposed buildings had sufficient clearance and accessibility for wheelchair users. Medical students have used VR to learn the relationships between the locations of internal organs. For our work we have produced three small modules for exploring the use of VR to view spatial relationships in chemical engineering.

The first two of these deal with face-centered cubic and body centered cubic crystal structure geometries, as shown in Figure 5. These modules contain a single unit cell and a lattice of 3x3 unit cells in

which the central cell is highlighted. Students can fly through the structures to observe the arrangements of the atoms from any viewpoint.

The third module illustrates fluid flow in circular conduits, as shown in Figure 6. A parabolic profile moves down the pipe, followed by tracers that are coded by both color and length to indicate their relative velocity. Students may enter inside the pipe to observe flow patterns more closely. Student evaluations of these two modules have not yet been completed.

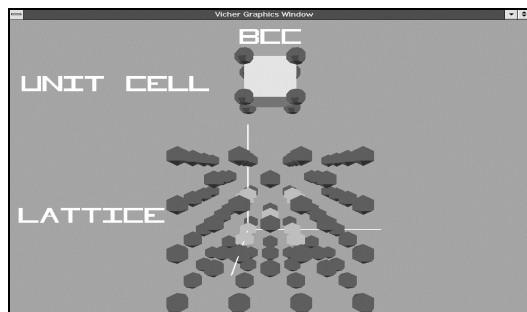


Figure 5: Body-centered cubic crystal structures - unit cell and 3x3 lattice.

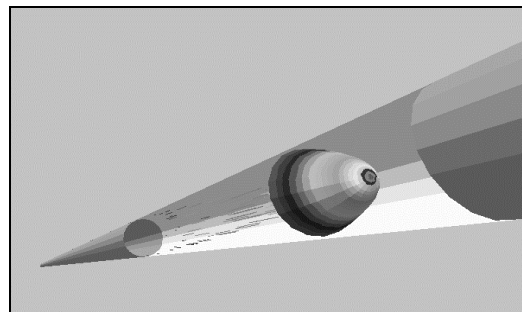


Figure 6: Color coded velocity profiles for laminar flow in circular conduits.

### **Information Space**

Another attractive feature of VR is the access it provides to information space - a land where there are no tangible objects, but only data and concepts portrayed in a variety of representations. There are two major issues to be investigated in this realm: "In what ways can students and engineers benefit from this ability?", and "How can the various components of VR ( color, motion, size, shape, etc. ) be best used to portray scientific and technical concepts?" Again, three small modules have been developed to explore these topics.

The first of these modules uses different characteristics to indicate properties of an ideal gas. A cylindrical shaped sample of gas ( removed from the classic piston-and-cylinder apparatus used to study PVT relationships ) bulges at high pressures, enlarges at high molar volumes, and changes color from blue to red with increasing temperatures. Entropy is indicated by sound, ranging from smooth and mellow at low entropy to a raucous cacophony at high entropy. The PVT application is shown in the right side of Figure 7.

In a further effort to explore information space, a module has been developed that attempts to illustrate Maxwell's relationships between thermodynamic properties and their derivatives. This module shows four energy surfaces (  $G$ ,  $H$ ,  $U$ , and  $A$  ) as functions of four independent variables (  $P$ ,  $V$ ,  $T$ , and  $S$  ). The partial derivatives of each of the energy surfaces with respect to the independent variables are indicated by vectors attached to the surfaces with the appropriate slope. Color coding is used to indicate the relationships between independent variables for one energy surface with derivatives of other surfaces. ( Maxwell's relations ) For example, volume is always green, whether shown as an independent axis or as a derivative vector. Students can change the pressure and molar volume of the system, and all other values adjust accordingly. This application is illustrated in the left side of Figure 7.

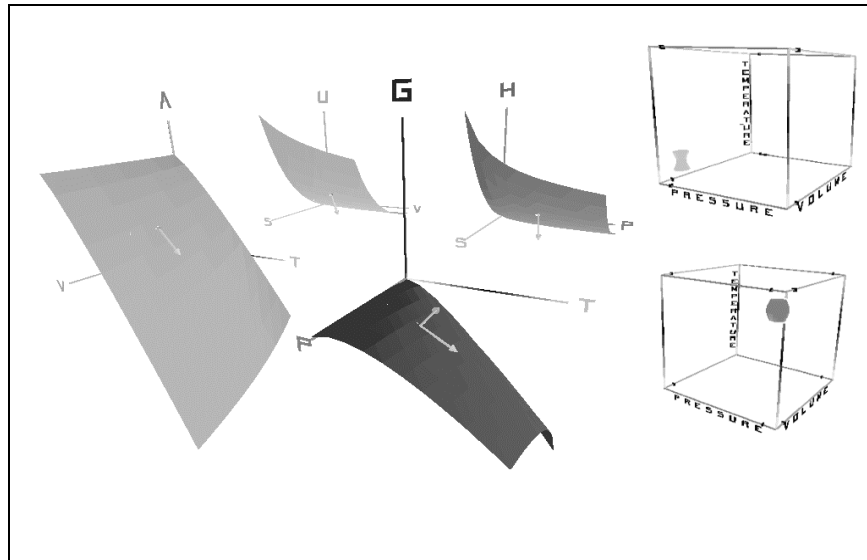


Figure 7: Maxwell's relations ( left ) and PVT relationships ( right ).

Also in information space, an industrial contact expressed an interest in viewing binary distillation residue curves of four component azeotropic mixtures using VR, and so the application shown in Figure 8 was developed. The framework is an equilateral pyramid, which acts as a three dimensional extension of triangular graph paper, with pure components located at each of the four corners of the pyramid. Color is used to indicate the chemical composition of any interior point, with the pure components represented by red, blue, green, and white. The lines that flow through the pyramid connect distillate and bottoms compositions for different feed compositions.

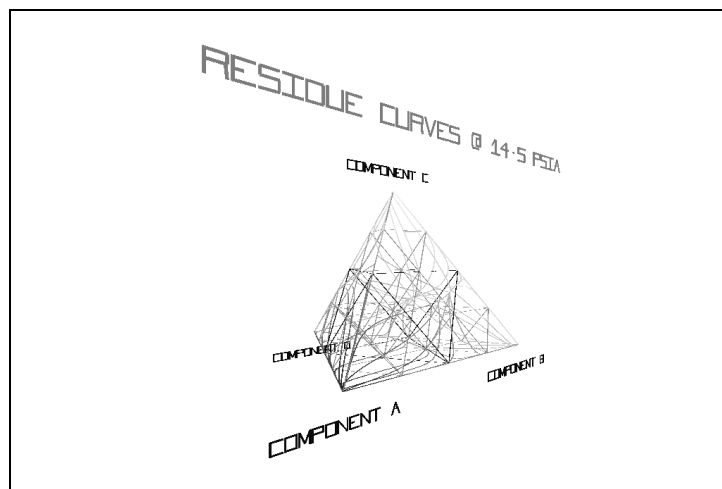


Figure 8: Four component azeotropic distillation residue curves.

## CONCLUSIONS

Great progress has been made over the past year, but there still remains much to be done. The final areas of the Vicher modules are under construction, but accompanying materials still need to be written and extensive testing remains to be done. Undoubtedly there will be necessary refinements revealed as a result of the evaluation process.

The safety module shows great potential, but requires extensive fleshing out before that potential can be realized. The other modules begin to illustrate some of the capabilities of VR, however it still remains to be determined how and where those capabilities can best be applied to engineering education.

#### ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the efforts of the undergraduate student programmers who have assisted in the development of the modules described here, specifically Christian Davis, Darren Obrigkeit, Shawn Way, Jeroen Spitael, Paul Sonda, Anita Sujarit, Scott Whitney, Adam Deedler, and Pieter Spitael, ( in chronological order. ) Thanks are also due to Dr. Joseph Louvar and Lawrence James of BASF Chemical Corporation and to Tom Pakula of Marathon Oil Company for the valuable resources which they have provided for the development of the virtual reality modules, and to the Department of Chemical Engineering of the University of Michigan for providing the initial funding of this project.

#### BIBLIOGRAPHY

1. Bell, John T., and H. Scott Fogler, "The Investigation and Application of Virtual Reality as an Educational Tool", *Proceedings of the American Society for Engineering Education Annual Conference*, Anaheim, CA, June 1995, pp 1718-1728.
2. Bell, John T., and H. Scott Fogler, "Vicher: A Prototype Virtual Reality Based Educational Module for Chemical Reaction Engineering", accepted for publication in the June, 1996 issue of *Computer Applications in Engineering Education*.
3. Cooper, D.J., "PICLES: The Process Identification and Control Laboratory Experiments Simulator", *CACHE News*, 37, 6-12.
4. Felder , R. M. and L. K. Silverman, "Learning and Teaching Styles in Engineering Education", *Journal of Engineering Education*, **78**(7), 674-681, April, 1988.
5. Fogler, H.S., S.M. Montgomery, and R.P. Zipp, "Interactive Computer Modules for Chemical Engineering Instruction", *Computer Applications in Engineering Education*, **1**(1), 11-24, 1992.
6. Kolb, D. A., "Experiential Learning: Experience as the Source of Learning and Development", Prentice-Hall, Englewood Cliffs, N.J., 1984.
7. Montgomery, Susan and H. Scott Fogler, "Selecting Computer-Aided Instructional Software", *Journal of Engineering Education*, **85**(1), January, 1996.
8. Pimentel, Ken and Teixeira, Kevin, "Virtual Reality: Through the New Looking Glass", second edition, Windcrest Books, 1995.
9. Rosendall, B. and B. Finlayson, "The Chemical Reactor Design Tool", *Proceedings of 1994 ASEE meeting*, Edmonton, Alberta, 1994.
10. Squires, R.G., P.K. Andersen, G.V. Reklaitis, S. Jayakumar, and D.S. Carmichael, "Multimedia-Based Applications of Computer Simulations of Chemical Engineering Processes", *Computer Applications in Engineering Education*, **1**(1), 25-30.
11. Stice, James E., "Using Kolb's Learning Cycle to Improve Student Learning", *Journal of Engineering Education*, **77**(5), February, 1987.



## BIOGRAPHICAL INFORMATION

### JOHN T. BELL

( Department of Chemical Engineering, University of Michigan, 3074 H.H. Dow Building, Ann Arbor, MI 48109-2136, ( 313 ) 763-4814, 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.

### H. SCOTT FOGLER

( Vennema Professor of Chemical Engineering, same address, (313) 763-1361, H.Scott.Fogler@umich.edu )  
Scott has over 130 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." Scott was the 1995 Warren K. Lewis award recipient of the AIChE for contributions to chemical engineering education.