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Introducing Virtual Reality Into the Engineering Curriculum

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Bringing a new technology into the classroom can be a difficult endeavor. This can be especially true if the technology itself is still evolving rapidly and has not yet been applied to technical education, and even more so if the technology is not perceived as a valid scientific endeavor by most faculty and university officials. This paper describes the steps taken to bring one such technology, virtual reality, into the chemical engineering curriculum, despite the many difficulties encountered along the way. The continuing journey from initial concept to widespread acceptance has been a difficult series of new frontiers, not unlike those encountered by the early explorers who founded this country so many years ago...

Pawning the Queen's Jewels

I first became interested in virtual reality (VR) in 1992, when three events occurred at about the same time: I first experienced VR in an entertainment application at the MegaMall in Minneapolis, I discovered some public domain VR software[1] on the Internet and started developing some simple worlds, and I attended the annual meeting of the American Institute of Chemical Engineers. At the latter event I attended most of the talks on modeling and simulation, and started looking around to see what was being done with VR in chemical engineering. What I discovered was that not only was no one using VR in chemical engineering, but few had even heard anything about it. Here I saw an opportunity to explore a very interesting area of research for which I was uniquely qualified. The next step was to convince someone that this was a serious research topic worthy of being funded.

I spent several months contacting various chemical engineering departments, trying to stir up interest in applying VR to chemical engineering before I finally made contact with a foresighted educator named Scott Fogler at the University of Michigan, whose interactive educational computer modules[2] had attracted my attention at the AIChE meeting. Scott replied to my e-mail that he was very interested in applying VR to chemical engineering education, but that he had found it to be prohibitively expensive. When I responded that I was already implementing VR in my spare bedroom with an old 386 based PC and $100 worth of extra parts, we commenced a dialogue that eventually led to my coming to Michigan in the spring of 1994.

We launched our expedition into the unknown with $25,000 of seed money from the chemical engineering department and the college of engineering, which we used to purchase two high-end personal computers, development software, and a few VR peripherals. Operating funds for student programmers and my own salary came from Scott's endowed chair and from the chemical engineering department in exchange for my teaching several classes. Our journey had begun.

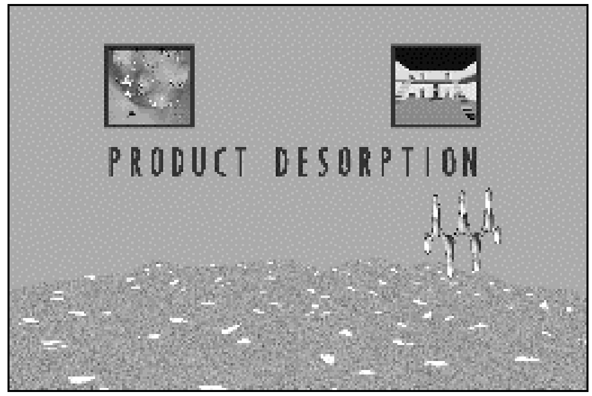
Founding the First Settlement

Our first major application was named Vicher (**Vi**rtual **Che**mical **R**eactor module), for the study of chemical kinetics and reactor design. Vicher initially contained three rooms (a welcome center, reactor room, and a debriefing center) and two microscopic exploration areas (the outside and inside of a catalyst pellet.) The welcome center and debriefing rooms were designed to introduce students to VR and to test what they had learned respectively. The main action occurred in the reactor room, where students could observe and control the activity of catalyst pellets within a straight-through transport reactor. In order to get a closer look, students could step inside the microscopic pores of any of the catalyst pellets and observe the mechanistic steps of catalytic reactions. A full description of the initial development of Vicher can be found in [3].

During those early development stages we learned a lot about what was and was not possible, practical, and effective in virtual reality based technical education. For example, the debriefing room was designed to test students' mastery of the material covered, but we quickly found many problems associated with questioning someone wearing a headset, so we temporarily abandoned that idea. We also discovered how to implement an operational virtual control panel, how to rapidly move complex objects (molecules, catalyst pellets) on student affordable hardware, how to deliver interactive help text, and the benefits of teleports over hallways for moving between rooms. We had a functioning product ready for initial student use.

Our next problem was getting the program into the hands of the students. Although we had deliberately chosen a student affordable computer platform (90 MHz Pentium PCs), the University of Michigan at that time was almost entirely Macintosh and UNIX workstation based, which meant that the only way that students could try out the programs was to come to my office. With 180 students in the two sections of the reactor design class, logistics prevented the use of VR as a required assignment. Instead it was offered as an optional activity (with no bonus points or other credit), which yielded 25 student test subjects in a one week period. We did get some positive feedback and good suggestions for improvement from our participants, but we had to take the results with a grain of salt, knowing that only those students excited enough about emerging computer technology to take time out from their busy schedule during the last hectic week of the semester had participated.

Establishing a Mature Colony

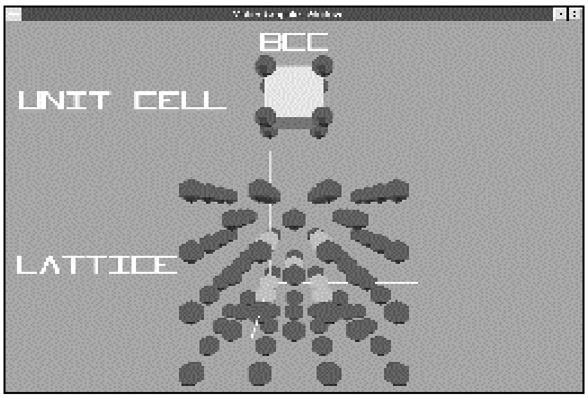


Over the next year Vicher grew and prospered, as did the VR capabilities at the university. Regarding the software, Vicher expanded and split into two modules, (Vicher 1 and Vicher 2, covering catalyst decay and non isothermal effects respectively) with a grand total of eleven different areas for students to explore. These included two welcome centers, six different reactor rooms, and three microscopic exploration areas. The most complete description of the current status of the Vicher programs can be found in [4].

The computing center at the engineering campus, meanwhile, purchased hundreds of new Pentium computers, and outfitted three of them with the joysticks required to run the VR programs. (Joysticks have since been made an optional equipment item.) Two inexpensive head-mounted display units (optional) were also purchased, and placed on reserve in the engineering library for checkout by those students wishing to get fully immersed in the virtual worlds. The next time that the reactor design class was given the opportunity to try VR (with a few points of extra credit), over a hundred evaluation forms were received.

At the same time, another major application, dealing with hazard and safety analysis, was prepared for student use. This module allowed students to explore a modern polyether polyol production facility to evaluate the hazards and safety systems present, as fully described in [5]. One hundred and fifty students from a first semester plant design class were given an assignment to analyze the safety of the facility using a written description and to also evaluate the virtual representation. (Half of the class completed the two tasks in that order, and the other half used both VR and the written description to analyze the safety of the plant.) The general response to the evaluations was that VR has great potential, but that the hardware and the software both need to improve before that potential can be realized. (The safety application had only undergone two months of development at the time of the evaluations.)

Excursions into the Wild



One of the major goals of our research effort is to identify and demonstrate what are the capabilities of VR, and how they can be applied to technical education. We have therefore produced a number of VR applets - small applications developed quickly as proof-of-concept vehicles - to explore particular techniques in VR as applied to varying situations. These applets have scouted out new territories in applying VR to crystal structures, fluid flow, pressure-volume-temperature relationships, thermodynamics, and azeotropic distillation. Although they have served their purpose in demonstrating some of the capabilities of VR, there are no immediate plans to develop these outposts into complete packages. (However some of the techniques involved have been incorporated into the larger applications.) More details concerning some of these applets are available in [6].

Spreading Across the Land

Now that the Vicher programs are reaching maturity, current plans are not to add any new areas to the existing Vicher programs. Rather the existing modules will be polished, streamlined, debugged, fine tuned, optimized, and generally prepared for widespread public consumption. Supplemental materials (i.e. manuals) will also be prepared. Hopefully the programs will be ready for off-site beta testing by mid July, and for initial widespread distribution by November. The feedback that we receive will then be used to guide further refinements and development of additional new modules.

In addition to expanding its territory geographically, it is also planned to port the Vicher programs to alternate hardware platforms, so as to reach a wider potential audience. (Vicher was deliberately developed using software libraries for which there is multi-platform support. [7]) Vicher was originally developed under Microsoft Windows 3.1, and in a matter of weeks has been 100% successfully ported over to Windows NT/OpenGL (with some hardware restrictions for optimal performance.) Porting to Silicon Graphics (SGI) has also been commenced, with about 80% success rate in early efforts. The limitations for the latter platform are caused by inherent differences in the hardware capabilities and by the fact that the initial SGI port was performed using a beta release of the software libraries on a borrowed (demo model) SGI workstation. Future hardware ports will be conducted using the facilities of the Virtual Reality Lab in the newly constructed Media Union on the University of Michigan's North Campus - a facility so new that as of this writing the VR equipment has not yet been ordered, or even firmly decided upon.

The Next Frontier:
In Search of a Killer (App)

To date we have illustrated many of the capabilities of VR as a technical educational tool, we have addressed many of the technical issues involved, and we now stand poised to deliver our first useful product to a nationwide audience. However there are still many observers whose response is "so what?" They look at what we can do with virtual reality and say "Well, what can you do with VR that you can't do (better) with books, pictures, movies, multimedia, or other simulations?"

Part of the answer to this question is that it depends upon the person. Different people learn and understand things in different ways [8-11]. Some people are word oriented, and can understand complicated topics easily from books and lectures. Those people tend not to get too much from VR, because they already understand the material from reading the textbooks. That's OK - those people don't need additional learning tools.

Other people, however, are either visually oriented or "hands-on" people, who do not really get a firm grasp of a concept until they experience it for themselves. Those are the people who do not learn as well from textbooks, and are most likely to learn from VR. Unfortunately for our impact on our professional colleagues, however, most successful engineering educators are very bright people who fall into the former category of people who learn easily from books and therefore see little additional benefit from VR.

This leads us into the search for the killer app - that elusive fantastic application that makes everyone take notice and say "Wow, I never even thought of doing **that** before!" (The classic example of the killer app is that personal computers were widely considered as toys until someone invented the spreadsheet. Now they are indispensable tools in every field of endeavor.) Whatever that wonderful application is, it must take advantage of the unique features of VR in a way that is both impossible to do any other way and is also worth doing - that is it must produce a tangible benefit that is unachievable through any other means.

The most notably unique feature of VR is the sense of "presence" - that feeling experienced by the user that he/she is really within the simulated world. So the next problem is to identify situations where it is readily apparent to all concerned that "being there" is significantly better than looking at books, pictures, movies, or ordinary computer simulations. An excellent analogy is in buying a house: A real estate agent can spend days or even weeks showing a prospective client statistics, blueprints, photographs, videotapes, paint samples, fabric swatches, and even sound recordings of the traffic noise and singing birds, but most people (especially first-time home buyers who are analogous to inexperienced students) will not buy a house without walking through it first hand. There is just something about that experience that cannot be duplicated by any other means. (This is why architects were some of the earliest pioneers into VR, to allow clients to walk through buildings that had not been built yet, with the hopes of completing most necessary design changes before any concrete was poured.)

Our next important goal then is to identify similar applications in chemical engineering for which there is (currently) no substitute for a plant visit. What are the tasks that force an engineer to leave his or her office and get on an airplane, in spite of telephones, flowsheets, P&I diagrams, photographs, video recordings, and computer simulations? If we can identify those tasks and solve those problems using VR, then we will have identified our killer app. (Anyone with any good ideas on this subject, please contact JohnBell@umich.edu.)

Reflecting Upon the Journey Traveled

In summary, these are some of the difficulties that we have encountered and/or expect to encounter soon in bringing VR from concept to widespread acceptance in engineering education:

1. Procuring initial approval and resources necessary to commence the project. Unproven and unknown technologies are given little support by administrators who do not foresee the potential value of the project and may not perceive the endeavor as a valid field of research.

2. Applying emerging technology to a situation for which it has not been previously used. The need to deliver quality technical information using low-cost equipment, for example, is not an issue in either the entertainment industry or military applications, which are the more well established uses of virtual reality today.

3. Providing sufficient student access to required non-standard equipment. Unless they can easily access the new technology at their convenience (i.e. late at night), few students will choose to participate in voluntary extra activities. This then raises potential problems with the maintenance and security of specialized equipment kept in a public computing lab.

4. Identifying the situations (classes, subjects, students) where the new technology will yield the most tangible benefits. Oftentimes a new tool is not well suited to solving old problems, but it may be invaluable for solving a new class

of problems that had not been previously considered. The difficulty is in finding that class of problems and showing that there is some benefit in solving them.

5. Making certain that the technology works on a widespread basis. So far our programs have been tested on a handful of different computers, and we have been able to resolve all of the hardware problems encountered. However as demos of our applications start reaching a wider audience[4], we are expecting to hear from new users with new problems.

6. <u>Proving</u> that there are real educational benefits to be gained by using the new methods. This is perhaps the most difficult to achieve, because it requires two groups of students (of a statistically significant size) who receive identical training except for the new technology being tested. If students are allowed to self select, then the groupings are biased and that must be taken into account, and if students are assigned to groups, then some students will feel they are at a disadvantage, and will cross groups surreptitiously. In our case we have seen some evidence of enhanced learning in some cases, but have not achieved any statistically relevant "proof".

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