Reprinted from *American Society for Engineering Education 1997 Annual Conference Proceedings*, Session 2313, Milwaukee, WI, 1997.

Undergraduate Research Experiences Developing Virtual Reality Based Educational Modules

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Introduction

Over the past several years a number of virtual reality (VR) based educational modules have been developed, using undergraduate chemical engineering students as the primary day-to-day program developers. These students had minimal computer programming and no VR experience prior to starting their projects, and some of the students had not yet completed the relevant engineering courses. There have been fourteen different students involved in the project to date, over half of whom worked on the project for only a single term. This paper describes the experiences of this group, including the advantages and disadvantages to all concerned.

The Project

Virtual reality is a computer simulation technique that incorporates interactive three-dimensional graphics, realistic sound, and often special display devices to create an immersive computer generated environment designed to fool the user into forgetting it is just a simulation. It is our belief that VR can become a powerful new tool in chemical engineering, and especially in undergraduate engineering education. However before this new tool can be effectively applied, we must first learn its strengths, weaknesses, and optimal implementation. A series of VR based educational modules have therefore been developed, in order to explore the capabilities of this emerging technology. The interested reader is directed to the listed references [1-7] and / or to the laboratory web site at http://www.engin.umich.edu/labs/vrichel to learn more details of the VR modules.

The Students

There have been fourteen students involved in the project so far, including the current four who are just beginning their involvement. Thirteen have been either Junior or Senior chemical engineering students, and one is a Sophomore in mechanical engineering. The University of Michigan requires a freshman computing class of all engineering majors; However none of the students involved had chosen C programming (most took FORTRAN), and the Juniors and Seniors were very rusty on the programming that they had not used since their freshman year. Nine of the thirteen chemical engineering students had completed the chemical reaction engineering course (the subject of the VR modules) prior to starting work on the project; The other four chemical engineering students were taking the reactor design course concurrently with their research on this project, and the mechanical engineering student had no association with any chemical kinetics course.

Nine of the fourteen students were previous students of one or more of the principal investigators on the project, and the remaining five were attracted to the project through public displays, demonstrations, web pages, and word of mouth. Ten of the students received one or more terms of undergraduate research elective credits for their efforts; Five were paid for their labors; And four worked at least part time just for the fun of being involved. (The sum of the numbers exceeds fourteen because several of the students worked for more than one term for different reasons.) Four of the students that have since graduated still provide occasional support to the project, in terms of technical information, beta testing, or other assistance.

The Work Involved

VR requires a wide range of computer and other skills, beginning in our case with extensive C programming. Our primary development tool has been the WorldToolKit (WTK) development package from Sense8 corporation [8]. WTK is a library of C functions that handle many of the low-level graphics and device interface chores of VR development. However our own programming, written primarily by the student programmers, currently exceeds 15,000 lines of code.

Besides C programming, the students also performed extensive graphics manipulations, both to provide detail for their virtual worlds and to produce suitable images for display, publications, and presentations. Some graphics images were scanned in from photographs. Others were captured screen images from spreadsheet graphs, molecular modeling programs, painting and drawing programs, and whatever other programs were appropriate. A few were taken from CD ROMs of royalty free images or similar sources. However none of these images could be used without minor or major retouching using one of the popular photo editing programs. Many of the images also required format conversions of various kinds.

The third major skill required of the students was three-dimensional object generation. VR works by maintaining, updating, and continuously redrawing a database of 3D objects that are defined in terms of their vertex coordinates, polygon normals, materials properties, and many other parameters. These objects must first be created, using one of many techniques. One such technique is to simply take pencil and paper and write down all the pertinent information. This can be fast and effective for simple geometrical shapes, but would not be practical for more complex objects. Common furniture geometries were obtained from CD-ROM libraries of AutoCAD objects, but more specialized objects required other techniques. A few of the students (most notably the mechanical engineering major with an interest in architecture) either knew AutoCAD previously or learned a little as part of their project. In addition, some special programs were written to generate objects, including a surface of revolution routine (assigned as an exercise) and a routine to generate the vertices, polygons, etc. for a pipe with multiple elbows, given key points along the pipe's centerline and a few other parameters. The students also developed a few creative and ingenious methods for creating and modifying their 3D objects.

And then there were a wide range of miscellaneous tasks that have been necessary for VR development, such as narration and other sound effects. One student was our graphics arts specialist for a while, handling most of the graphics image manipulations and web page development. Another concentrated on the development of interactive "help" and hyperlinked graphical documentation. Students have taken computers apart, changed hardware components, and reassembled them after road trips. (The latter task is complicated by the number of special external devices and switch boxes connected to our machines.) The VR modules have been demonstrated at many off-campus and on-campus events, the latter of which often involve students conducting the demonstrations. All of the students have learned a little about human psychology, cognition, and computer-human interfaces, in order to persuade the users to believe their simulations with a minimum number of polygons.

Student Response

In preparation for writing this paper, attempts were made to contact the ten students who have completed their work on this project, to get their reflective opinions of the benefits and drawbacks of their experience. Responses were received from six, as described here. Some of the quotes are exact, and some are paraphrased slightly while maintaining the original meanings. All students quoted are being given a chance to review and edit this document prior to submission of the final copy.

Student 1 was one of the first two students working on this project, and is now working as a chemical engineer for Michelin Tire Company in Spartanburg, South Carolina. After completing two summer half-terms for credit, he continued to work on the project as an hourly paid employee until his graduation the following spring, during which time he helped direct the work of newer students in addition to his other duties. Part of his response reads as follows:

> *The greatest benefit I received from working on the Vicher project was the experience and practice of "algorithmic thinking" and logic. Learning to break complex tasks into small pieces and solve each small problem individually has been a tremendous asset in the industrial world.*
>
> *Even at a tire plant, computer skills are highly regarded. Thus the computer experience and knowledge I gained from the Vicher project have been tremendous assets.*

He then goes on to explain how he has used his computer skills in his new position, and to consider the possibility of using VR to train new employees in an industrial setting.

Student 2 was the other of the first two students, and is now pursuing graduate studies in chemical engineering at Massachusetts Institute of Technology. Because of various logistical issues, these two students started working on the project before all the principal investigators were present, and as a result these students were heavily involved in evaluating, selecting, and ordering the equipment for the project. Student 2 found his experience to provide valuable insight into the world of research:

> *The Vicher project outlined what research would be like in graduate school. It was the first time that I had been given this amount of autonomy in deciding the fate of a project. I was forced to very quickly learn a lot about VR equipment. I was constantly asking myself, "Will this really work?" Currently, as I am trying to decide on a topic for my thesis project, I often ask myself the same question.*
>
> *I discovered that the heart of research is a moving target visionary dream of what could be done, with the researcher ever making progress towards that goal, doing whatever is necessary to reach that goal - changing the approach to the problem, trying different solution methods, etc.*
>
> *I realized that the horizon of things considered "research" is much broader than I had originally supposed, including algorithms, programs, VR, etc. - i.e., more than just experiments.*

Student 3 started helping out that first summer just because he thought it was a cool project, (and he was a close friend of student 2.) The following term he worked on the project for undergraduate research credit, and has provided occasional assistance ever since. (He still lives in the area, and stops by every now and then to see how things are going and perhaps to lend a hand.) This student was well known around the department as a computer whiz - other students and even faculty would regularly call upon his skills in Mathematica, and he is still providing the department with Mathematica programs for undergraduate use even though he graduated over a year ago. Some of his (paraphrased) reflections on the project read as follows:

> *What I received out of the research project was the formal training in another computer language. One of the main reasons that I became involved with the project is to keep up with the latest innovations of computer technology in chemical engineering, and a personal interest in virtual reality. Call it curiosity.*
>
> *The reduction of complex engineering concepts to numerical methods was fascinating, although a little confusing at times.*
>
> *One of the drawbacks was the dual supervision, leading to uncertainty about what was expected in the final project. This was also a benefit, since we were able to see "management decision" in action.*

He then goes on to suggest that we branch out, and apply VR to other areas of chemical engineering besides just chemical reactor kinetics, with some specific suggestions.

Student 4 worked on the project for double credit (20 hours work per week instead of 10), and is now a sales engineer for Weskem Hall in Texas, although he is applying for graduate school admission in business administration. His response explains how he came to have a much deeper understanding of catalyst properties and behaviors from working on this project that he ever would have from the traditional textbooks alone. (He had already completed the reactor design course before commencing work on this project.) One paragraph from his letter reads, in its entirety:

> *I feel this project greatly enhanced my knowledge of catalyst (porosity, activity, and decay) and their effects on reactions through the discussions and directed studies that Dr. Bell provided prior to and during programming. I do not know if the class has guided me into my current position, but I do know that I had a better understanding of catalysts and plant applications after I left my research project. Subsequently, I am currently a sales engineer who trouble shoots plant applications and promotes catalysts and adsorbents to refineries and petrochemical companies.*

Student 5 was perhaps affected the most by her experiences on this project, in terms of influencing future career decisions and opportunities. She happened to decide to get out of chemical engineering as a result, but if we can help students find their true vocation, that is more important than steering them or keeping them within a particular field. Some of her (abridged) comments read as follows:

> *I was an avid gamer and beginning to learn more about computers when I saw your presentation at AIChE. My interest in chemical engineering and medical school was dropping, and I saw the VRiChEL project as a perfect opportunity for me to find out if computer graphics was the field for me.*
>
> *Since the project team was small, I was exposed to many aspects of computer graphics: concept design, programming, web page development, and graphic design. The best part was to be able to see the big picture, which helped me make my career decisions. I gained a lot of hands-on experience in computer graphics that even EECS people don't get. How many people get to work with VR on the undergraduate level? Even* [another major VR lab] *is made up of mostly graduate students.*
>
> *As an impact on my career choice, after being exposed to computer graphics from VRiChEL, I soon realized that computers and computer graphics were a lot more interesting to me than chemical engineering or medicine. After that I tried to learn as much as I could in school, by taking a computer graphics class and working for different computing labs on campus.* [Including a neighboring lab with more advanced VR equipment than was available in our lab at the time.]
>
> *In industry I worked for Sigma6* [a local graphics arts company] *and Microsoft. Even though I graduated with a degree in chemical engineering, the work experience that I gained in school was great and the companies were very impressed with it. I even got an offer from one company in San Francisco whose job listing required 5 years experience in computer graphics!*

Student 6 is now a senior, preparing for graduate studies in chemical engineering. Some of his (paraphrased) thoughts on his undergraduate research experience are as follows:

> *It really helped me in learning to work on my own. At first it was awkward to not have set due-dates for specific tasks, but then I started to enjoy the freedom and the confidence that came from knowing that I could set reasonable goals for myself and attain them with little further guidance. There is a certain satisfaction from knowing that other people are counting on your work, and that I was able to deliver. Although this was not a "research" project per se, it still developed the type of skills that will be useful later on when I enter grad school. I think the project was a fair representation of the problems I am likely to face in a professional career.*
>
> *What will probably benefit me most later on is learning the C language. I also have a deepened interest in computers in general, and especially in the promise of virtual reality. VR is both a fascinating new area of interactive computing and also a very powerful educational tool.*
>
> *Another aspect crucial to this work was the need to pick up where others left off. Many people have collaborated on this project, and it was sometimes challenging to dig through their work and try to decipher what they had accomplished. This stressed to me the need for proper documentation when working on parts of a larger puzzle, i.e. the need for a clear line of communication from one student to the next. This project illustrated to me how important it is to communicate effectively.*
>
> *Overall, I would say that working on the VR project was a positive experience. It gave me a chance to see some positive results in a relatively short amount of time, while all too often it is hard to see the fruits of your labor. It was exciting to be part of this promising new technology, which might very well become commonplace in the not so distant future. That was one of the exciting parts of working on this project rather than some more "real" chemical engineering laboratory project.*

The Project Directors' Perspective

From the point of view of those directing the research, there are both advantages and disadvantages to working with undergraduate research assistants:

Advantages

1. One of the most obvious advantages is the cost/benefit ratio. Students working for credit or for fun consume few research dollars; Hourly undergraduate employees cost less than graduate students, and may or may not incur benefits and overhead costs. Every student who has worked on this project has made real progress, and has been well worth the associated costs.
2. In some cases, undergraduates may be all that are available or appropriate. In a school that does not have a graduate program, or when the principal researcher is not a tenure track faculty member, it may not be possible to assign (other) graduate students to the project.
3. There is a certain joy in working with truly bright undergraduate students in a cooperative, conflict-free relationship without constant tensions over grades, homework, exams, and even-handed fairness to every student in the class.
4. Likewise there is a satisfaction inherent in having a positive impact on a young person's development, as evidenced by the comments collected above. Of course there is some of this in every course we teach, but the effect is more profound and more evident in the close working relationship of a research project.
5. For this particular project, the undergraduate researchers had a better understanding of the needs and perceptions of the target audience, and in addition were able to deliver anonymous "grapevine" feedback from their peers to the project directors.

Disadvantages

1. The most difficult aspect of working with undergraduate researchers is the necessary learning curve, and the limited duration of their usefulness before graduation. Half of the students who have completed work on this project were only available for a single term, and all the students required C programming and VR training before they reached their full potential. The seniors brought more experience and knowledge to the project, but also had the least longevity between learning the necessary techniques and graduation.
2. Undergraduate students, in general, require more direct instruction and guidance than graduate students, therefore requiring more of the project directors' direct attention. This becomes less true as students become more experienced.
3. Undergraduate students have more time conflicts with their other class schedules and responsibilities. This problem arises both in terms of scheduling group meetings and in reduced productivity when other classes have pressing assignments.
4. There can sometimes be awkward situations if an undergraduate researcher is simultaneously taking a course taught by his or her undergraduate research advisor. Although all the students on this project are completely trustworthy, it is still important to make certain that questions of fairness never arise.

Conclusions

Incorporating undergraduate assistants into research projects is extremely beneficial for all concerned, and should be highly encouraged. Although there are some difficulties (as noted), the benefits strongly outweigh the drawbacks.

Benefits to the students vary widely, depending on the individual's situation. Some of the advantages reported by the students include specific skills (e.g. C programming, graphics skills), improved thought processes when tackling complex projects, preparation for future (graduate) research work, a deeper understanding of the engineering concepts involved, improved confidence in independent abilities, and an understanding of the importance of effective communications when working as part of a larger team. Several students reported using the skills gained in this work in later employment, and in one case this project lead directly to significant career decisions and employment opportunities.

Benefits to the project and project directors include the joy of working closely with bright students, the satisfaction of having a positive impact on young people's lives, and the useful work produced by the undergraduate researchers at a reasonable cost. Drawbacks include the limited time between completing training and graduation, time conflicts with other student responsibilities, and the larger time commitment required of the project directors (as opposed to working with graduate students.)

Acknowledgments

The author would like to gratefully acknowledge the efforts of all the undergraduate students who have worked on this project, and in particular those who have provided information for this paper, as indicated by underlined names in the following list: Chris Davis, Darren Obrigkeit, Shawn Way, Charles Stevens, Jeroen Spitael, Paul Sonda, Anita Sujarit, Scott Whitney, Adam Deedler, Pieter Spitael, Jeremy Brotchner, James Angelo, Jessica DesNoyer, and Kim Snodgrass. Thanks are also given to Tom Pakula of Marathon Oil Company, and to Joe Louvar and Larry James of BASF Chemical Corporation for technical information and assistance, and to the National Science Foundation who have provided funding for this project under grant # DUE-9555094. (Views expressed are those of the authors, and do not necessarily reflect those of the foundation.) The author would also like to thank and acknowledge the co-director on this research project, Vennema Professor H. Scott Fogler of the Department of Chemical Engineering at the University of Michigan.

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