Enhancing the Engineering Design Process with a Virtual Reality VRML World

Stephen W. Crown
Department of Mechanical Engineering
University of Texas – Pan American

Abstract: The design process begins with careful investigation of a problem and how the specific design will address that problem. Access to the environment under study is necessary throughout the design process however access is often impossible or impractical. In engineering education the need for students to have access to the environment under study is critical as they develop in their understanding of the design process and use of design tools. Access to these design environments, however, is generally more difficult in education. An interactive virtual reality VRML world was developed to open the door to some of these environments and enables investigation and interaction in such a way that the entire design process can be carried out on the computer. The VRML world has been used in an Engineering Graphics Course to teach the design process and the use of Pro-Engineer. The VRML world is a Roman encampment against an enemy fortress. Students are charged with the task of capturing the fortress occupied by the enemy through the design of siege weapons using Pro-Engineer. The Roman encampment is populated with soldiers that teach computer-aided design. The virtual world allows for interaction with other students, the instructor and lab assistants, and occasional visitors from outside the university. The Roman VRML world was designed for adaptability and served as a template for other virtual environments including a virtual international space station. The initial impact on the Engineering Graphics course and the methods used to develop the virtual world are described. A web-based faculty development resource is described that is available to assist in the development of like materials and as a repository for developed materials.

The Design Process
Engineering Graphics is an excellent course for introducing freshman-engineering students to the design process since it plays an integral role in the process of design. Several key aspects of the design process, however, are often missing or greatly abbreviated in student design projects for practical considerations. The first step of the design process is to clearly identify the problem. This is done through careful investigation of the environment. In the engineering graphics course students are challenged to design a catapult that could be used in the siege of a third century enemy fortress using tools and materials available at the time. A visit to the third century fortress would yield many insights into the necessary design requirements and would help students understand the importance of investigation prior to the generation of solutions. Some of the observations that students could make from such a visit are the terrain around the fortress, the height and strength of the walls, and the width and strength of the bridge that must be crossed to reach the fortress. Obviously students cannot visit third century Europe. Other design projects could be selected, however there are often constraints such as cost, location, or time that also prohibit careful investigation of the environment under study.

One of the final steps of the design process is to implement the design and see the solution put
into effect. This step of the design process is also generally missing or abbreviated from student design projects. This, however, can be one of the most rewarding steps of the design process as students see their ideas actually put to use. Not only is this a step in the design process that students should be familiar with it is an important step in the process of effective learning. In the book How People Learn: Brain, mind, experience, and school (Bransford et al) the authors introduce the importance of anchored learning where learning is centered around a challenge. The idea of anchored learning has spawned the legacy learning cycle which emphasizes the importance of “going public”. Knowing that their ideas are entering the public realm and will be compared, reviewed, and critiqued are an essential motivator.

VRML

The virtual reality modeling language, VRML, opens the door to investigation and interactivity and facilitates simulation of the entire design process on the computer. The virtual world allows students to thoroughly investigate the environment and develop appropriate design criteria based on observations. It may also be used as a mechanism for simulating the implementation of designs and provides a platform for presenting designs in the public realm and receiving feedback. The virtual world can be easily accessed through a plug in on an Internet browser.

A Roman world was created in VRML to create an environment for students to learn, explore, and present ideas. The world shown in Figure 1 consists of an enemy fortress and an encampment called the training camp where forces are being built in preparation for a siege against the fortress. The enemy fortress is a walled city with over sixty residences. After the successful siege, students will occupy the fortress and take up residence in one of the homes in the walled city. The students enter the virtual world as a new recruit in the Roman army to receive training in the building of catapults using Pro-Engineer. At the end of their training, they will work in small groups to design and build their own catapult. The catapults will be constructed in Pro-Engineer and saved as VRML models that will be imported and used in the siege of the fortress. After the

![Figure 1. VRML Roman world used in Engineering Graphics course.](image-url)
successful siege the catapults and other student designs will be displayed in their private residences in the VRML fortress shown in Figure 2 in the VRML fortress. The interior of the private residences is a small VRML world that resides on each student’s personal web page. The house interiors are linked to the house exteriors in the walled fortress. A sign on the exterior of the each house identifies the owner. Clicking on the door brings the user into the student’s home. This gives the students control over their own space while maintaining an integrated virtual world.

The personal residences are arranged into camps as shown in Figure 3. The camp structure is used to encourage group participation. Students select their own residences and then meet their neighbors. Their first group activity is to design a sign for their camp that appears in the entrance to the camp in the virtual world. Other group activities include exploring the virtual world together to collect information for the catapult design. Students must work in pairs as they observe each other pace off measurements of the wall and bridge. Several students must climb on each other’s shoulders to determine the wall height.
Interaction between students in the virtual world is accomplished with an open source Java program running on the server. The Java program keeps track of each member’s movements in the virtual world and allows for text-based chat. Figure 4 shows students in the virtual world interacting with each other and the instructor. Students log in using their real names and can...
choose from a variety of avatars (3D characters). The program allows for private or group conversations although all conversations are recorded on the server. The chat allows for interaction between students and with the instructor or lab assistants even from remote sites. Chat in the virtual world is effective since the conversation is enhanced by the visual images. When the instructor enters the world to explain the mechanism on the catapult in Camp C students congregate around the catapult and focus on the topic of conversation. Small models of the catapult that can be manipulated and taken apart in the virtual world allow students to closely examine the design.

The training camp is organized into six camps (A-F) that the students visit in order. The leader of Camp A is Marcus shown in Figure 5. There are twelve soldiers in Camp A that each teach the

![Figure 5. A pop up instruction page for Marcus in Camp A.](image-url)
student some aspect of building the catapult base in Pro-Engineer. Clicking on a soldier in the virtual world launches a pop up instruction page. From the instruction page a full screen audiovisual tutorial movie is started that walks the student through the use of Pro-Engineer. The student simply follows along in Pro-Engineer as they see and hear their instructor walking them through the program. Figure 6 shows a tutorial movie from Camp C where the student is receiving training on creating ball joint connections for mechanisms in Pro-Engineer. The virtual world is populated with over sixty soldiers who give a total of several hours of full-screen real-time screen capture movies in the use of Pro-Engineer.

In Camp A and B students view the parts used to make a catapult and then see the parts assembled. They copy drawings make the individual part in Pro-Engineer guided in each step by the soldiers in the tutorial movies. As the students complete Camp B they are sent to Camp C with a letter of recommendation and challenged with reverse engineering a captured catapult. The
soldiers in Camp C give general instructions about the techniques used but do not give specifics about the catapult design. The students must examine the catapult and make their own working drawings. From their working drawings they will build the catapult in Pro-Engineer. Completion of Camp A-C takes the students about six weeks. At the end of this training they are prepared to build their own catapult design in Pro-Engineer.

**Development**
The conception, creation, and implementation of the virtual Roman world took approximately 240 hours over the course of six months. A significant portion of that time was spent learning how to use software and dealing with specific problems in implementation. The world however can easily be recreated or significantly modified in a small fraction of that time. To facilitate the use and redevelopment of similar virtual worlds a web site ([http://www.engr.panam.edu/~toolbox](http://www.engr.panam.edu/~toolbox)) has been developed for educators, that serves as a repository for developed materials and as a resource for developers. Other educational materials such as the use of interactive games in the teaching of engineering graphics (Crown, 2001) are incorporated into the site.

The VRML world was created with a world-building program called Spazz3D. The program is one of several programs available that simplify the process of creating the objects, textures, and

![Figure 7. Layout of VRML world structure in world building program.](image-url)
animations that comprise the virtual world. The entire VRML world is a series of linked text files that follow a standard called VRML 2. The VRML language has a useful structure shown in Figure 7 that was exploited in the development of the roman virtual world. Objects can be grouped, named, and referenced to simplify the creation of complex worlds. A single tent was created in the training camp and then referenced for all other instances. Using such a structured format has allowed the creation of new virtual worlds by the simple replacement of components in the world. A space station, for example, was created by replacing the tents with space capsules and other similar modifications while keeping the general structure the same. A virtual campus is also under development using the same structure.

The links to student pages use a feature called an anchor, which is simply a linked object that launches a defined URL. The links to all the student pages are kept in a separate file so that they can be easily updated each semester. The students download the VRML houses that students run on their own web pages. The objects in the house are built in Pro-Engineer and then linked to their house using a VRML feature called inlines. This allows the students to update and their virtual house without modifying the VRML files. Pro-Engineer allows for files to be saved using an earlier version of VRML (version 1), which is incompatible with most new VRML browsers. The files however can be easily converted in Pro-Desktop or with a VRML utility program.

The chat server is an open source program called Vnet+ that runs on several platforms since it is written in Java. There are several companies that will host VRML chat worlds for an annual fee however the functionality and simplicity of the Vnet+ program was sufficient for this application. The server has easily supported over thirty users at one time however the chat is easier to follow if multiple chat environments are used to accommodate large groups.

**Impact on Students**
Students were introduced to the virtual world during the first lab session and accessed it frequently throughout the course. Students expressed enthusiasm about the virtual world and quickly began interacting with the environment and making significant observations related to the catapult design project. There was also great interest in the virtual residence where students could furnish them with virtual models of their designs. Many students placed images and objects inside their virtual homes outside of the required class assignments. In a number of cases students modified early designs on work that had already been graded simply to update the items in their virtual home. Students would often ask about the schedule of visitors and many expressed interest in keeping the site active after the course was over so that they could continue to exhibit their work.

Many materials have been developed and implemented in the engineering graphics course (Crown 1999) that have already shown a significant impact on student performance. There were however two significant changes observed in the classroom with the introduction of the virtual world. Typically several students drop the engineering graphics course in the first few weeks. In the first semester that the virtual world was introduced the first student drops occurred after the first midterm and fewer students dropped the course. Additionally, a significant increase in group interaction and productivity was observed. The quality of student work improved as a reflection of a better understanding of the problem, better group participation, and a greater interest in
seeing the project through to completion. Logs of the chat reveal that students primarily use the chat for personal conversation mixed with discussion and questions about the course and assignments. The free and open exchange between students, often unrelated to the course material, was a likely contributor to the positive group dynamics observed in the classroom and an increase in retention.

**Conclusion**

The engineering design process is enhanced through the use of VRML by providing a rich interactive design environment that provides for the presentation and display of ideas. The ability for students to explore and interact with the environment of a design problem helps them develop necessary design skills as they establish appropriate design criteria. The VRML virtual world makes such exploration possible in the classroom. Additionally, the ability to see the implementation of a design and make it public is a great motivator for the students. The VRML virtual residences that reside on the student web pages serve this purpose. The addition of chat and the interaction of avatars in the VRML world stimulates interaction among students and was a likely contributor to increased group productivity and student retention.

The virtual Roman world houses hours of instructional material related to the design of a catapult in Pro-Engineer. The world, however, was conceived as means of introducing students to a variety of design environments and design tools. The Roman world was converted into a virtual campus and a virtual space station to provide a variety of design environments. The instruction offered by soldiers in the virtual world is presented using screen capture movies and could be easily modified to teach other design tools and any topic appropriate to the world environment. A web site is available to facilitate the use and development of virtual worlds in education and to enhance the design process.

**References**


**Acknowledgements**

This work has been supported by the National Science Foundation (CCLI-0089035) under a project entitled “Implementation of Pedagogies for Interactive Computer and Web-Based Undergraduate Learning.”