Virtual Explorers: 
An Alternative Approach to Teaching Digital Rapid Visualization 
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Introduction
The significance of digital technology in industrial design has been widely acknowledged for many years. As the scope and applications of design technology grow, designers are relying more and more on computers to aid in the design process. Ensuring that design practitioners and students understand the potentials of these new technologies and are adequately prepared to utilize them is the focus of this study.

This paper will present a pedagogical tool which introduces a methodology for using digital design technology. It will demonstrate how current design technologies can be used in a more effective manner to visualize new product concepts.

In winter 2008, the author led a three-week intensive course titled Digital Rapid Visualization for Industrial Design at Arizona State University in order to illustrate the significance of this methodology and its applications. The course objective was to introduce design students to the methodology and exploration of digital technologies in industrial design practice. A total of 17 students registered for the course; 4 industrial design (ID) graduate students, 1 graduate student in Human Factors, 8 ID undergraduate students, and 4 undergraduate students from Design Studies in the College of Design made up the class. Over the three-week winter session, there were 14 class sessions lasting three and half hours each from Monday to Friday in the college computer laboratory. The course was composed of class lectures, which were complemented by hands-on projects. The learning objectives for the course included introduction to and practice with 2D digital tablet sketching, 3D form sketching, 3D digital scanning, 3D surface and solid engineering modeling, 3D virtual rendering and animation, and 3D rapid prototyping. Students did a design project in which they explored the process of digital rapid visualization. This combination of presentation, demonstration, discussion and experimentation allowed the students to experience real world applications of these emerging technologies during the design process.

This paper offers an overview of some of the digital design technologies used in new product development, and uses the course as a case study to demonstrate the pedagogical value of learning by doing.

Course Descriptions and Goals
The purpose of this course was to introduce a methodology of using digital design technology and to explore how those technologies are currently used in industrial design practice to effectively visualize concepts.

In the first class, it was clearly explained that this course was not designed to teach students the use of computer software, but rather focused on exploring the process of digital rapid visualization through use of diverse applications and tools. Students were exposed to new digital technologies and processes through in-class assignments. This “learning by doing” teaching methodology enabled students to understand how design technologies could be effectively used to develop better, faster, and more accurate design outcomes. With a successful completion of this course, students would be able to 1) explore and practice diverse digital design technologies, 2) understand the importance and methodology of digital design processes, and 3) discover new applications using the technologies introduced in the course.

Course Outlines and Schedules
Given the tight time restrictions and compressed nature of the three-week course, each class was designed to include lectures, demonstrations and ample time for student hands-on experimentation. The course curriculum, including schedule and class topics, is illustrated in Figure 1 below.
Digital Design Technology
More than ever, product design determines product success. To keep up with rapidly changing consumer trends, designers need specialized tools to develop, communicate and produce compelling designs within tight deadlines – plus the flexibility to make changes throughout the design process (Alias Systems Corp, 2004).

Several software applications optimize the creative design process, allowing sketching, modeling, and visualization tools to quickly bring ideas to reality. Three-dimensional visualization during the early design phases is the principal use of these tools and strategies. They include a fairly wide range of stand-alone sketching programs, geometric modelers, and renderers. SketchUp, Alias SketchBook Pro, Painter, Photoshop and PlanDesign are common sketching programs. Geometric modelers primarily used for conceptual design include programs such as Rhinoceros, and conceptual modelers with strong emphasis on rendering are, for example, Form-Z and 3D Studio Max. Since many users find data input through mouse and keyboard cumbersome, sketching programs often enable to input data by drafting on interactive tablets in a manner similar to sketching on paper (Schodek et al., 2005).

Using 3D digital scan technology, reverse engineering has become a feasible method by which to create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE and other software applications (Varady, Martin & Cox, 1997). 3D prototyping technology provides designers and engineers the ability to explore design alternatives, test theories and confirm
performance prior to starting production of a new product. For communication and documentation, 3D virtual rendering, animation, or product demonstration videos are created using a number of different digital design applications.

Case Study – Teaching the Process of Digital Design

1. 2D Digital Sketching (Class 1 – 5)

Many different ways of visualizing ideas have been explored in design practice. Sketching on paper is a quick and traditional method of design communication. However, digital visualization has accelerated the way we present concepts in the product development process. Since the introduction of digital tablet technology, designers and artists can now quickly edit, render and visualize their work for communication. In order to introduce the technology of digital sketching, the first class started with drawing basic geometric shapes and simple products in Painter using a Cintiq tablet monitor manufactured by Wacom. Based on this exercise, students learned and explored basic tools of the program, digital sketching skills and digital tablet technology while visualizing their design concepts.

Figure 2. Samples of Digital Sketches

In the next class, different digital sketching techniques were introduced. Instead of drawing from scratch on the tablet monitor, students performed detailed digital sketches on scanned perspective line drawings using Cintiq and Painter. This exercise demonstrated to students how pen or pencil sketches could be quickly turned into effective digital visual communication materials.

2. 2D Digital Rendering (Class 6 – 7)

There are many computer programs that can create vector lines. Rhino—a non-parametric feature-based surface modeler, that also can be used for drafting, rendering, and animation—is one of the most common programs that industrial designers have been using for three dimensional modeling and line work. For about two hours in class, students learned how to draw 2D orthographic view lines using the basic tools of line, curve, and line edit. Line drawings created in Rhino can be saved as Illustrator files (.ai) and opened in any vector-based graphic program. One of the most important procedures during the line work in Rhino is to ensure that lines and curves of each part are closed and joined as one object. Then, all parts must be assembled together to be saved as an .ai file. This allows each part to be selected to add color or materials in Illustrator. For example, the mouse rendered image shown in Figure 3 was created with 7 different parts of closed lines in Illustrator CS3. Based on the vector lines, using Gradient, Mesh Gradient, and Type tool in Illustrator CS3 a 2D orthographic view rendering was created by a student following along with a 15 minutes real-time demonstration by the instructor.

To explore a bitmap-based rendering program, Photoshop CS3 was used to fabricate a 2D rendering using the same vector lines. In order to bring the vector lines from Illustrator to Photoshop as path, the lines have to be selected and copied in Illustrator (using Ctrl+C) and pasted in Photoshop (using Ctrl+V). If this procedure is not followed, all vector lines will be rasterized to a bitmap image in file importing and will not show as vector paths. Once imported, paths can be converted to selection marqueses to add colors, gradients, patterns, filters, or other effects for the orthographic view rendering. With an awareness of the differences and similarities between the two types of 2D graphic programs, students were able to learn how to quickly render
their concepts in two different digital formats. Moreover, students learned key-points in file conversions and explored tool features in each program.

![Figure 3. Samples of 2D Digital Rendering (left-line work at Rhino, middle-Photoshop, right-Illustrator)](image)

3. 3D Form Study Model (Class 8)
The primary purpose of a 3D form study model which can be made out of diverse materials (such as foam, paper, clay, wood, foam-board, wire, etc.) is to explore the overall shape of the model and study human factors while making a three dimensional model.

The orthographic vector lines can cut the materials used for study models using laser cutter technology, which allows for accuracy. When making a mouse study model, it is recommended that the outlines of the top view should cut the form material and the side profile shaped using hand tools and sand paper. The overall design should reflect an exploration of form and human factors. By adding other materials such as clay or play-dough, the design can be modified and explored as a part of 3D sketching process.

It is also accurate enough to cut the form material with a utility knife and other surface finishing tools by hand based on the full-scale rendered image glued on top of the form.

4. 3D Scanning of Form Study Model for Reverse Engineering (Class 8)
A 3D scanner is a device that analyzes real-world objects or environments to collect data on shapes and appearances, including color. The collected data can then be used to construct digital three dimensional models, which in turn can be used in a variety of applications. These devices are used extensively by the entertainment industry in the production of movies and video games, and also this technology can be used in industrial design, reverse engineering and prototyping.

Reverse engineering is essentially initiated from three dimensional data collected by the 3D scanning technology: 1) tactile probe – mounted on a machine tool or a coordinate measuring machine, 2) non-contact sensor – optical triangulation range sensor (Chan, Bradley & Vickers, 1996). As computer-aided design has become more popular, reverse engineering has become a viable method to create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE and other software. One of the primary benefits of this technology is that the device can precisely transmit the 3D data of design details including human factors explored in 3D form study models to the 3D computer modeling program. Since 3D scanned models can be saved as both surface and mesh, they can provide dimensions and design profiles in both surface and solid modeling programs.

There are several different types of 3D scanners: 3D digitizer, 3D laser scanner, 3D&4D ultrasound, and hand gun type of 3D scanner. In order to scan the mouse 3D study model, a desktop 3D laser scanner called NextEngine was demonstrated in class.
5. 3D CAD Modeling (Class 9 – 11)
Throughout the product development process, CAD/CAM tools are extensively used by both designers and engineers for design presentation, manufacturing, and engineering analysis tasks such as mold-flow, finite-element analysis, and collision and impact simulations (Schodek et al., 2005).

In industrial design education, many design schools teach surface and solid modeling programs. The most popular freeform NURBS (Non Uniform Rational Basis Spline) surface modeling programs being taught in industrial design education are Alias StudioTools, Maya, and Rhinoceros 3D. Pro-Engineer and SolidWorks, which are the most common solid modeling programs, are used primarily to teach engineering analysis and rapid prototyping.

Based on the 3D scanned mouse model, students learned how to convert 3D entities to a new computer model in Rhino. The mouse.obj file saved in a 3D scanner program was imported in Rhino, along with dimensions and other design details such as button size, parts, and parting lines that were clearly recognized from the 3D model. This method translates the accuracy of human factors data studied throughout the 3D form sketch and allows the precise profiles of the design in rebuilding a new 3D computer model. Basic Rhino menus and tool explorations with tutorial based materials were taught for one class session, and then the next class was dedicated to a step-by-step demonstration by the instructor of how to build the overall body shape of the scanned mouse in Rhino.

The mouse surface model was then saved as a STEP file and imported in SolidWorks to make parts (buttons, top, and bottom) with wall thickness and shell using the background image of the scanned model. The main purpose of using two different modeling programs was to explore the strengths of each program. Rhino (based on a non-parametric system) allows industrial designers to explore formal variations such as geometric or organic shapes, while SolidWorks (based on a parametric system) offers enhanced performance for radius corners, part split, bosses, ribs, wall thickness and the shell as an engineering tool. Through this CAD modeling assignment using Rhino and SolidWorks, students were able to learn and understand the differences and strengths of each program.

6. 3D Rapid Prototype (RP) (Class 12)
Rapid prototype serves to simply, accurately and quickly communicate the new product design in a form that makes the intangible concept physical and real. Among the three modeling options (wireframe, surface wireframe, and solids), only the wireframe model which is conducted with edge definition is not suitable for rapid prototyping applications (Grimm, 2004).

The mouse CAD model initiated in Rhino and completed in SolidWorks with wall thickness and shell was saved as a STL (Stereolithography) file which is composed of a mesh of triangular elements and a neutral file format that any CAD system can feed data to the rapid prototyping process. Using two different rapid prototyping technologies, FDM (Fused Deposition Modeling) and a 3D printer, the mouse model was built using the Dimension SST and Z-Printer 450, both housed in the college computer lab. This allowed students to explore the benefits and compare the printing cost, time, and the surface resolution of each prototyped model. The details of this collaborative class comparison exercise are shown in Table 1.
Table 1. Rapid Prototype Comparison Chart

<table>
<thead>
<tr>
<th>Prototyped Model</th>
<th>Prototyping Equipment</th>
<th>Materials</th>
<th>Print Time</th>
<th>Print Costs</th>
<th>Surface Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension SST (FDM)</td>
<td>ABS</td>
<td>Model: 2.12in³</td>
<td>Print: 4.5 hours</td>
<td>Model: $21.2</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Support: 1.39in³</td>
<td>Bath: 3 hours</td>
<td>Support: $13.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z-Printer 450</td>
<td>Plaster</td>
<td>Powder: 2.1in³</td>
<td>1 hour 20 mins</td>
<td>Power: $2.51</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Binder: 27.9ml</td>
<td>Surface: 52.8in²</td>
<td></td>
<td>Binder: $4.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Surface: $2.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Print head: $1.68</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Labor: $1.75</td>
<td></td>
</tr>
</tbody>
</table>

From this case study of RP comparison, students learned which RP technology would be more suitable to visualize their design and more efficient to meet the primary purpose of RP, such as part assembly, functional testing, tooling analysis, or aesthetic visualization with product color and materials.

7. 3D Virtual Rendering (Class 12 – 14)

As the last major step in the graphics pipeline, the 3D virtual rendering provides the final appearance of the models with color, materials, and graphics. There are a number of different 3D virtual rendering software packages that are integrated into larger modeling and animation packages, stand-alone, or plug-in using different render techniques: 1) Scanline rendering and rasterization, 2) Ray casting, 3) Radiosity, 4) and Ray tracing.

The digital rendering of the mouse was created from the two different applications, V-ray on 3D Max Studio and Hypershot, both which use HDRI (High Dynamic Range Imaging) allowing a greater dynamic range of luminances between light and dark areas of a scene than normal digital imaging techniques. These techniques were introduced and taught in class using instructor-generated tutorials that students followed along with and replicated. The tutorials were made in Photoshop CS3 with multiple layers which explained the steps from file importing to material editing and lighting setup. In addition, the Photoshop digital file (.psd) allowed student to take their own notes on each layer using a tablet pen so that they could keep the file with their own notes for future work. The images shown in Figure 5 visualize the two computer models and render outcomes. Through this rendering exercise students were able to understand the primary purpose of digital virtual rendering and explore the differences and similarities of the two different programs.

Figure 5. 3D Modeling and Virtual Rendering (from left: Rhino, SolidWorks, V-ray in 3D Max Studio, and Hypershot)
Lessons and Conclusion
There are countless digital technologies including software that are being introduced in design practice and education. The mouse project gave students the opportunity to explore how rapidly, easily, and precisely their concepts could be visualized through the process using the digital applications and tools introduced in class.
In addition, this new learning experience in digital design technology enabled students to successfully:
• gain an awareness of how digital design technologies can be used in industrial design
• understand how different design technologies can be used in different ways to support their own design interests
• learn and apply new digital design technologies in several steps of the process of new product development
• learn how to visualize design concepts through digital design media.

This paper provides one example of how rapid digital visualization can be taught. It is crucial that students be kept abreast of new technological developments that shape industrial design practice. Instructional strategies like the ones offered here contribute to an evolving understanding of requisite tools in industrial design and how to prepare students to master them.

References


