From Virtual to Physical: Rapid Prototyping as a Tool to Integrate Graphics in a Mainline Engineering Class

M. Whiteacre & J. Dorribo Camba
Department of Engineering Technology and Industrial Distribution
Texas A&M University, College Station, TX 77843-3138

ABSTRACT *– One of the main problems faced by engineering graphics is the inability to get mainline engineering classes to recognize the benefits graphics can provide when it is properly integrated into the curriculum. By using solid modeling and rapid prototyping it is possible to have students design and produce physical parts which can be used for analysis and physical tests. This paper reports our efforts to incorporate engineering design graphics and production into a project-based engineering course by using solid modeling applications and rapid prototyping tools. Project assignments used to implement this initiative as well as the approaches used both by instructors and students are also discussed.*

I. Introduction

Texas A&M University is part of a group of schools that, in 1993, initiated a National Science Foundation's program called the "Foundation Coalition". One of the objectives of this program was to increase the retention of students in engineering areas by integrating Math and Science more closely with Engineering and creating a project-driven approach to teaching at a freshmen level (Howze et al, 2003).

The freshmen engineering program at Texas A&M consists of two courses: ENGR 111 and ENGR 112 (Foundations of Engineering I & II). Both courses contain elements of engineering science and engineering graphics with the intention of having each part supporting the other. Such courses were formulated to replace the previous program of study where engineering science and graphics were taught in separate courses. However, this plan was hard to implement in the classroom. For many years, engineering science and graphics existed harmoniously within ENGR 111 and ENGR 112, but without much true support. Common examples were used and the two complimented each other, but little common ground was found in the projects to lend actual aid or assistance.

II. Background

The projects given in ENGR 111 and ENGR 112 are presented to the students as challenges that replicate situations similar to those in actual industry settings. Project tasks include analysis, design, construction, programming, testing, and documentation of the results. For the last several years the freshmen program has used the LEGO Mindstorm® system as the main tool to implement these projects. The projects have been varied in scope and focus, ranging from heat transfer measurements to wheel chair lifts (Froyd et al, 2005) to Ferris wheels to the current project, an autonomous vehicle.

Two years ago, the freshmen program acquired a FDM (Fused Deposition Modeling) rapid prototype machine that works with ABS plastic. This system was used during the first year to allow instructors to introduce rapid prototyping as a concept and to expose students to this technology. The instructors produced some prototypes and used them in their lectures. However, during the spring 2009 term another use for the system was envisioned. Since students were using the LEGO Mindstorm® system for the creation of their semester-long projects, parametric modeling tools were utilized in the graphics portion of the course, and a rapid prototype system was able to manufacture parts from ABS plastic, it would be possible to use all three of these components to actually support each other.

III. Project Description

The current assignment given to students in ENGR 112 consists of constructing and programming a vehicle, capable of carrying a 12 oz full soft drink can, which must navigate a pre-defined course without human intervention. The project is presented as a real situation where toxic waste (the soft drink can) must be transported safely to a storage facility. In order to reduce the risk of contamination to humans, an autonomous vehicle acting as a toxic waste hauler is required for this job. The particular task list which a vehicle is required to demonstrate is:

1. The vehicle must be able to detect the existence of a black line and/or a white line against various colored backgrounds (mainly the tile floor in the hall) using one or more light sensors. This information may be used to stop, start or steer the vehicle.

2. The vehicle must be able to follow a predefined path (marked on the floor with 2" blue painter's tape) using 1 or 2 light sensors. This path will not be entirely straight but may have bends no greater than 90 degrees.

3. The vehicle must be able to steer a straight line for a specified distance using synchronized angle sensors and motors. Also, it must be able to perform accurate dead-reckoning navigation depending upon circumstances; for example, 90 or 45 degree turns using only angle sensors and motors.

4. The vehicle must be able to sense large obstacles, such as walls and 11"x17" boxes, in its path and avoid them using an ultrasonic distance sensor.

5. Through a combination of dead-reckoning and obstacle sensing it may be possible to detect smaller obstacles such as ping-pong balls or empty soda cans.

6. Sound and touch sensors may be used to stop and start the vehicle; touch sensors may also be used to sense solid objects.

Figure 1 shows the course that the autonomous vehicle was required to complete. The grid shown is a standard 1 foot tile grid.

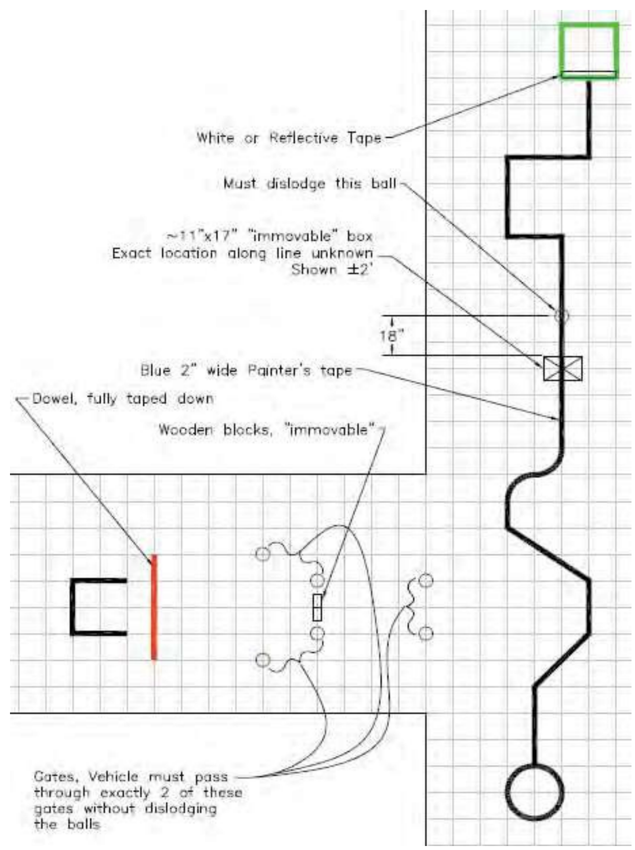

Figure 1. Course for the autonomous vehicle

Students were arranged in teams of 3 or 4 members and given the project assignment. Approximately 300 teams completed the project challenge in the spring 2009 semester. However, two small classes (20 teams) were selected to participate in a revised version of the project. These two classes were given the opportunity to create a virtual model of a new LEGO-ish piece using solid modeling software and then to have that part produced with a rapid prototype system. These new custom parts would be embedded into the design to enhance the overall performance of the vehicle.

IV. Instructor Approach

From an instructional point of view, there were two main goals behind this assignment. First was to enhance the spatial visualization abilities of the students and second was to provide real world exposure to the design process. Leopold states that spatial visualization abilities are especially important for those working in the field of engineering (Leopold et al, 2001) and McGee noted that visualization skills have been found to correlate highly with success in engineering and mathematics (McGee, 1979). Going even further, spatial visualization has been shown to be helpful in engineering related subjects like mathematics and calculus (Winkle, 1997; Battista et al, 1989).

Engineering design is widely considered to be the central or distinguishing activity of engineering (Dym et al, 2005) and he goes on to define engineering design as a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives of users; needs while satisfying a specified set of constraints. In our case the objective was to improve the functionality of the autonomous vehicle and the constraints were to work with existing standard LEGO® parts.

The use of virtual or physical models has long been used as a way to enhance spatial visualization. Many authors (Whiteacre et al, 2001; Miller, 1992; Vander Wall, 1981) have discussed the proper usages of either virtual or physical models prepared by the instructor to improve the student's ability to visualize objects.

By using the solid modeling capabilities of modern CAD applications students are capable of producing their own virtual models. By extending these capabilities via rapid prototyping they can actually make their own physical models. This process allows the students to see the virtual model and the physical model side by side, similar in some ways to the work done by Onyancha where a virtual and physical model were presented to students with the orientation of the physical model linked to the orientation of the virtual model (Onyancha et al, 2007). He concluded that these methods did improve the spatial ability of the students.

The instructions given to the students to manufacture the prototypes follow the basic steps of a design process. First, students were asked to gather information and identify the functional requirements of the design. This was accomplished through a brainstorming session where students identified limitations with their vehicles and recognized problematic areas where a custom LEGO® part would be helpful. After several discussions among team members and different freehand sketches, students decided and refined the purpose of their design (improving the stability of the vehicle, reinforcing the structure, etc). The second step was to identify the type of information needed to create a functional part. In most cases, dimensions of a standard LEGO® block gave the students the starting point to begin modeling. Students were required to submit technical orthographic drawings of the new part plus a stereo lithography file (STL) so the part can be produced.

In addition to the basic instruction on the design process, some specific guidelines were given about the process of rapid prototyping and how the parts needed to be constructed to be both useable and efficient. The prototyping system available has a maximum build volume of 8” x 10” x 10”, thus the parts had to be no bigger than this. Also, all parts should be shelled to save material and reduce weight; however, any surface less than 1 millimeter in thickness is likely to not be structurally sound when the build material is removed.

V. Student Approach

The idea of producing a physical LEGO® part from a 3D model created in the computer seemed to get students excited. Their reactions even when the instructors were presenting the assignment were very positive and students immediately began to discuss the assignment within their teams.

After approximately an hour of brainstorming and deliberation the concepts for the custom part fell into one of three broad categories: improving the maneuverability of the vehicle, providing structural support for the soft drink can to keep it in a stable position, or purely aesthetics. The latter seemed to be the default position when a team could think of nothing to actually help the design, but they were required to include a custom part in their final vehicle. Figures 2, 3, and 4 show examples of each of these three uses.

Figure 2. Part to improve maneuverability

Figure 3. Part designed for structural support

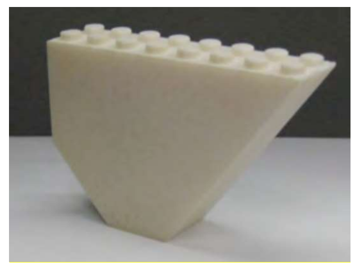

Figure 4. Aesthetic part

The modeling process provided an excellent opportunity for students to practice and improve visualization skills. From the very beginning, students were required to mentally visualize the custom part and figure out how such part was going to fit and interact with the existing structure. Students were forced to constantly move from freehand sketches to physical parts on the vehicle to virtual 3D models in the computer. According to students, processing all this graphical information provided an excellent learning experience.

For most students, this was the first exposure to having to create a virtual model of a part that did not yet exist. Additionally, having to size the part precisely showed many students why accurate measurements and dimensions are critical in engineering design.

While most LEGO® parts are relatively easy to model with solid modeling software because of their rectangular shape (in many cases only few extrudes and cuts are required), the tolerances for a LEGO® piece snapping into place or either falling apart or not fitting are rather small. LEGO® claims its mold tolerances are within 0.002 mm (LEGO 2007)Different approaches were taken to dimension the parts correctly. One team had access to a micrometer and took precise measurements of the existing LEGO® parts and shared those with any team who asked. Others did some basic internet research and sized their parts using that information. One of the teams did provide a teachable moment when they used centimeters as a base unit for creating their part, but set the software units to millimeters. When the part was manufactured it was obviously very small and could not be incorporated into the vehicle.

VI. Production of the Parts

After designing the parts, students submitted stereo lithography files (STL) to their instructors. IT staff processed such files and produced the prototypes including the cleaning in a chemical bath to remove the support material. Approximately 25% of the prototypes did not work for different reasons (wrong tolerances, inaccuracies in the design, large sizes, etc). In this case, students were given a chance to revise their files and resubmit them for reprocessing.

A few lessons were learned while producing the parts. It was found that producing the parts upside down saved build material and reduced clean up time. In the future a maximum size (especially height) should be specified to reduce the build time for the parts. Also, the importance of shelling the 3D model was explained when two identical parts, one shelled and the other one solid, were produced. Students were given the two files and instructed to submit them to a rapid prototype company website and get an estimate of how much it would cost to produce both parts. At the same time, students were asked to weigh each individual part and estimate the impact they would have on the vehicle.

The majority of the teams were able to incorporate their prototype within their vehicle, although in some cases some forced fits were required to assemble the prototype to the LEGO® structure. Figure 5 shows an example of a custom part assembled into a vehicle.

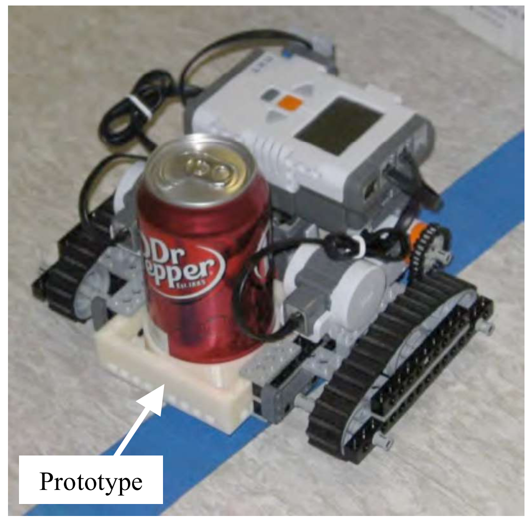

Figure 5. Example of Vehicle with Custom Part

VII. Conclusions and Future Work

The objective of our work was to incorporate graphics into a project-based engineering course in a practical way, motivating both students and instructors to take advantage of these tools. Rapid prototyping offers excellent possibilities to achieve this goal. Not only were the participating students influenced in a positive way, but they also were forced to practice visualization skills and discovered the significance of good design and the importance of precise measurements. In addition, rapid prototyping opened new possibilities for instructors, such as extending existing projects and conducting physical tests on a real design.

Although a promising initiative, no comparisons between experimental sections and traditional sections of the course were done to assess the effectiveness of this approach. The two classes selected to use the rapid prototyping system were honors sections, which used LabView® to program the LEGO® NXT controller as opposed to Robolab®, used by the traditional sections. These differences made a meaningful comparison difficult at best, so no attempt was made.

In the future we hope to eliminate these sectional differences and to actually measure the benefits of using rapid prototyping by comparing parameters like total time to complete the assigned task, or stability of the autonomous vehicle. We will also like to assess the impact of rapid prototyping on the perception of the students about engineering.

VII. References

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