Session #____

Rapid Prototyping to Cement CAD Modeling Skills

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Introduction

An important aspect of contemporary mechanical engineering education is mastery of a modern solid modeling computer-aided design (CAD) software package. This important skill is vital to future engineers' careers and gives students immediately marketable skills for summer employment. Students also need to learn important accompanying topics of engineering design.

In 1956, Benjamin Bloom headed a group of educational psychologists who developed the classification of levels of intellectual behavior important in learning that is known as Bloom's taxonomy.[1] As seen in Figure 1, these levels within the cognitive domain become increasingly more complex and abstract. The goal in learning is to progress up these levels.

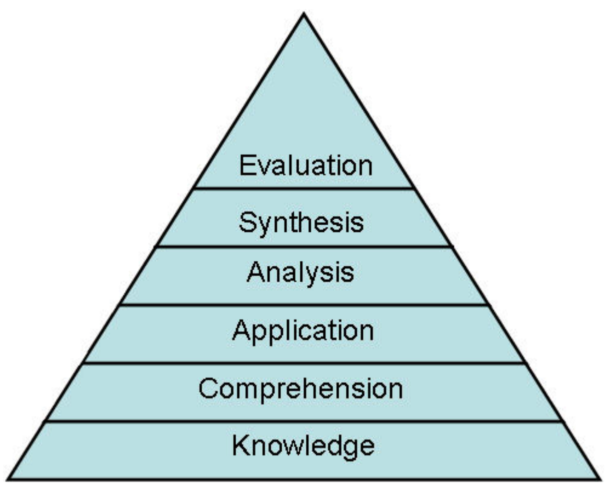

Figure 1. Bloom's taxonomy.[1]

Learning to use a CAD program can be done in three progressive steps that essentially follow the first three levels of Bloom's taxonomy, each step more open-ended than the previous:

1. Following a tutorial (gaining knowledge)
2. Modeling an existing part (testing comprehension)
3. Creating a new part from scratch (application)

In this paper, I discuss how these steps are implemented in a large-size, required first-year engineering graphics course in the mechanical engineering curriculum. The third step is emphasized and illustrated through a unique rapid prototyping project in which students design a new body for a radio-controlled model car that is subsequently fabricated through the generous contribution of Protogenic, Inc., a local firm that specializes in stereolithography.[2]

Course Format

Computer-Aided Design and Fabrication is a required three credit-hour, first-year course for mechanical engineering majors. While traditionally offered in the spring semester, we are moving the course to the fall semester next year, for several reasons. We find that having students learn CAD modeling early greatly benefits their performance in the required *First-Year Engineering Projects* course, which is a hands-on, design/build experience. Also, CAD modeling is an excellent introduction to mechanical engineering. And, if students gain CAD proficiency in their first year, it opens up possibilities for internships in subsequent summers.

There are two aspects to the course:
- Gaining a working knowledge of CAD solid modeling (SolidWorks[3] software)
- Learning theoretical concepts of engineering design, including orthographic projection, auxiliary views and sectioning, dimensioning and tolerancing (including geometric dimensioning and tolerancing), and basic manufacturing processes.

The course provides one, 50-minute lecture, and two, two-hour labs weekly. Not surprisingly, most of the learning of CAD skills occurs in the labs that are taught by undergraduate teaching assistants (TAs) who are chosen for their performance as a previous student in this course, as well as a good working knowledge of SolidWorks. Lectures present the theoretical concepts listed above, and provide an overall context of mechanical design, including the important topic of design for manufacturability (see reference 4 for a discussion on using virtual CAD parts to assist the learning of geometric dimensioning and tolerancing). A representative from Protogenic delivers a guest lecture on rapid prototyping technology. Lectures include hand drawing exercises that have a two-fold purpose: to sharpen manual drawing and visualization skills, and to break up the tedium inherent in any lecture.

Lab Projects

Tutorials — Since this is an entry-level course, no prior knowledge of engineering graphic skills is assumed. A tutorial is like a recipe: following the steps exactly guarantees the expected result. This is important because a powerful solid modeling CAD software package such as SolidWorks can be overwhelming at first exposure. A good tutorial partitions the learning process into a sequence of relatively simple steps, each of which builds confidence as success is achieved.

While the SolidWorks application includes excellent on-line tutorials, we prefer to use a textbook such as Lueptow,[5] which also includes limited-time, but fully functional, SolidWorks software so students can work independently outside of lab. One of the desirable features of this text is that while it steps students through the construction of a relatively simple product (a pizza cutter), it introduces many modeling, assembly and drawing capabilities of the software. Approximately five weeks are spent on structured tutorials.

Independent Project — Once students are comfortable with basic CAD modeling skills, they spend about two weeks creating a CAD model and associated engineering drawings of a relatively simple existing product with at least three separate parts. This requires both individual part modeling and assembly. In consultation with their TA, each student chooses their own product to model, which increases their "buy in," as opposed to an assigned project. Past examples include a clock, electric guitar, Swiss Army knife and a model boat.

Rapid Prototyping Team Project — The real test of mechanical design proficiency is the ability to envision and create a part that does not yet exist — an example of the third level of Bloom's taxonomy (application). In addition, if that part can be actually fabricated and fit into an existing assembly, it makes the abstract design process more vivid and real for the student. After all, "it always works on paper!" — or nowadays, the CAD terminal.

Rapid prototyping provides an excellent way to achieve these objectives because it can produce a complex part directly from a CAD model. Of the several rapid prototyping technologies available, one of the more widespread is stereolithography (SLA), which uses an ultraviolet laser to harden a liquid polymer (Figure 2). The resulting prototype is accurate, and can be finished and painted. Protogenic, a local prototyping firm that specializes in stereolithography, has generously supported this project since 2003, enabling students in this course to turn virtual CAD models into hard reality.

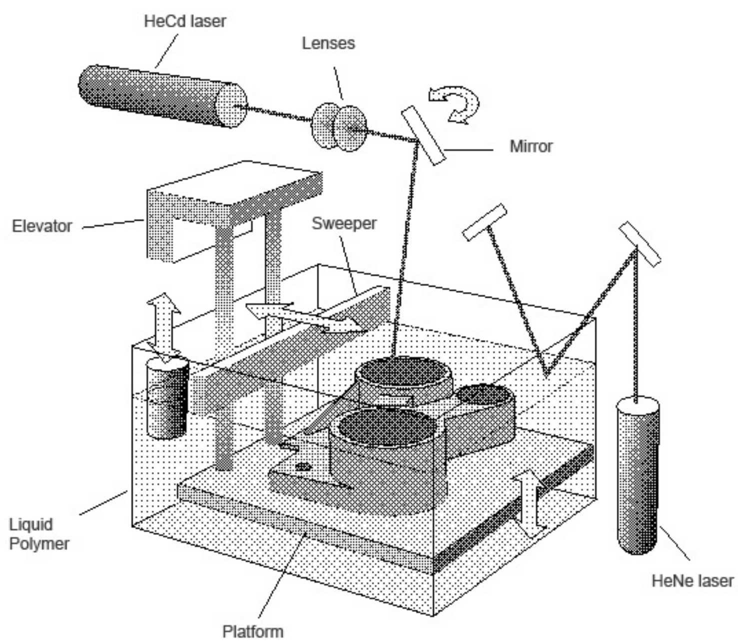

Figure 2. Stereolithography uses a laser to harden layers of a liquid polymer.

Students work in small teams to design new bodies to fit the chassis of a micro radio-controlled (RC) model car that they purchase for less than $20. Each team is given a maximum allowable part envelope of 2" x 2" x 3". This small size for each body allows Protogenic to either build many projects simultaneously, or to work several bodies into existing jobs as space allows. Each year, Protogenic has built up to 65 projects, with a commercial value of more than $7,000.

Creativity is emphasized — students are explicitly told they do *not* have to create a car. Past examples include a shopping cart, "wiener-mobile," shark and a garbage truck (Figure 3), as well as the inevitable tanks and jeeps. Students demonstrate their vehicles, which are expected to fit the RC chassis, at final team presentations. Each team also creates a CAD model of the entire vehicle, as well as accompanying engineering drawings.

Figure 3. Example stereolithography (SLA) projects. The yellow wire is the radio control antenna.

Benefits and Pitfalls

In this teaching approach, there are many learning benefits for students. They get to experience first-hand a state-of-the-art fabrication technology that may be valuable in their professional careers. Working in teams is an important aspect of the course, while the individual project seeks to ensure that each individual student masters basic CAD modeling. The importance of careful measurement and tolerancing is reinforced by the requirement that the vehicle must fit the RC chassis and be driven under remote control.

This project tends to stretch students' CAD skills because the types of projects they choose typically contain more complex geometry than the pizza cutter tutorial earlier in the course. With

TA guidance, students learn advanced topics in greater depth such as sweeps, lofts, use of symmetry, shelling and joining parts.

Each body is kept for a year and showcased, with the team members' names, in a prominent display case. This engenders a sense of pride in the students, and also sets a standard for creativity and quality of finishing and painting for the next class. In addition, projects are shown on the course and Protogenic websites.[2]

One drawback of this project is that Protogenic requires several weeks of lead time because these projects are of lower priority than their paying clients. However, working to firm deadlines is certainly an important experience for students.

Protogenic benefits by exposing several hundred students annually to this new technology, and of course to their company. Their goal is that a student who graduates and brings this technology to his/her new position will become "the star on their new job," in the words of a Protogenic staff liaison. We have also negotiated official acknowledgment of their contribution to the university, with tax benefits for the company.

Assessment

While there was no formal assessment of the final stereolithography project, it is clear that students enjoy the project, and learn a lot from it as well. For example, more than half of the students indicated that this project was one of the most effective aspects of the course on the standard course questionnaire administered at the end of the course.

Conclusion

A unique aspect of this project is that while there is a range of quality of the final products, virtually every team feels successful. There is a strong sense of pride among team members, and a healthy sense of competition between teams.

Acknowledgement

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Biographical Information

LAWRENCE E. CARLSON is founding co-director of the Integrated Teaching and Learning Program and Laboratory, as well as professor of mechanical engineering. He received his M.S. and D.Eng. degrees from the University of California at Berkeley. His primary educational passion is real-world design. In addition to CAD, he teaches a first-year engineering projects design/build course and an upper division *Innovation & Invention* course.