A Freshman Design Experience Using RPT

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Introduction

California Polytechnic State University has an earned reputation as a proponent of the hands-on, laboratory-based, learn-by-doing approach to education. We have also won a reputation as a college whose students are steeped in open-ended problems and underpinned by an understanding of design and the process of design. Design exposures for General Engineering students start in the second quarter of the freshman year. This early exposure is a retention tool, as it helps students begin to understand a facet of their professional life, and provides a glimpse at the world of the professional engineer. It provides a simple answer to the basic question "What will I do as an engineer?" Furthermore, the exposure provides connection to industry. The challenges students address in the class are components of problems provided by industry. This connection provides an answer to the question "What sort of companies will I work for?" In addition the exposure provides a segue to a continuum of future design experiences, answering the question "What other classes can I take?" Finally, the design exposure also panders to a basic human need. Design is not only the central and defining activity for the engineering profession, it is clearly the most human of all activities. The behavior sets us apart from all other species and has often been used to define what is human as opposed to simple animal conduct.

There is often a reluctance to treat design during the freshman year. Arguments are made that students lack the basic mathematical, scientific and analytical skills to make design exposures significant. This is a dangerous and destructive belief. A universal characteristic of engineering application is that tools and phenomena are used long before they are completely understood. (Thermodynamics owes more to the steam engine that the steam engine owes to thermodynamics!) One insidious result of delaying design exposure is that students mimic their instructors and carry forward a serious intellectual flaw. They begin to classify and compartmentalize knowledge, and neither integrate information nor make connections between disciplines. This is particularly critical in the freshman year, where students are exposed to mathematics, chemistry, physics and computer science – taught in isolation. These subjects should under gird their design skills and form connective threads in the tapestry of their professional awareness. Instead, they build silos in their consciousness, become unwilling to approach comprehensive problems and are incapable of holistic solutions. In the worst case this can lead to student frustration culminating in the loss of bright and well-motivated students to other educational disciplines.

Faced with these pitfalls and challenges, the design experience described in this paper was established specifically to satisfy the need for a meaningful design course in the freshman year. This course eliminates the student confusion engendered by a conflict between what they are told engineering should be - stressing intellectual integration and curricular synthesis - and what they perceive each day in their own educational experience. In designing the course, the goals were to help retain students, provide for close industrial participation, and to provide an integrative vehicle at a critical stage in the student's educational career.

Rapid Prototyping Technology as an Integrative Solution

Whereas textbooks have traditionally defined the *boundaries* between engineering disciplines, engineering education reform will require packages that *integrate* diverse concepts – "containers" providing the resources for student-initiated, hands-on, problem-based learning. These containers must be constructed around a topic that captures the imagination of students and encourages them to view technology with a holistic perspective. They must show the interrelationships between engineering disciplines and link engineering to the biological sciences. They must express mathematical and scientific concepts within a socio-economic framework. They must enable mentor relationships between educators and students, whereby the learning process is a non-linear, joint exploration that includes collaboration with colleagues and with industry. Few technologies offer a scope of applications as broad as *Rapid Prototyping Technologies (RPT*), while being accessible enough for freshman-level students with limited engineering exposure. Because of this, RPT is an ideal tool for modern engineering education.

Rapid Prototyping is an important developing technology that enables the fabrication of custom objects with novel properties directly from computer data. The basic operation of any RP system consists of slicing a 3-D computer model into thin cross sections, translating the result into 2-D position information, and using this data to control the placement of solid material. This process is repeated for each cross section and the object is built up one layer at a time (Figure 1). Rapid Prototyping has historically been associated with manufacturing environments, where it is used for the rapid production of visual models, low-run tooling, and functional objects.[1] The impact of RP goes far beyond these applications, however. For example, the input data for a Rapid Prototyping model can be an existing object scanned using lasers or medical imaging technology (CT or MRI). Because this technology is both increasingly accessible and easy to use, and provides an immediate link from the virtual world to the physical world, it is seeing increased use as a tool for study and communication in fields as diverse as biomedical engineering, electronics, aerospace, architecture, and archeology.[2]

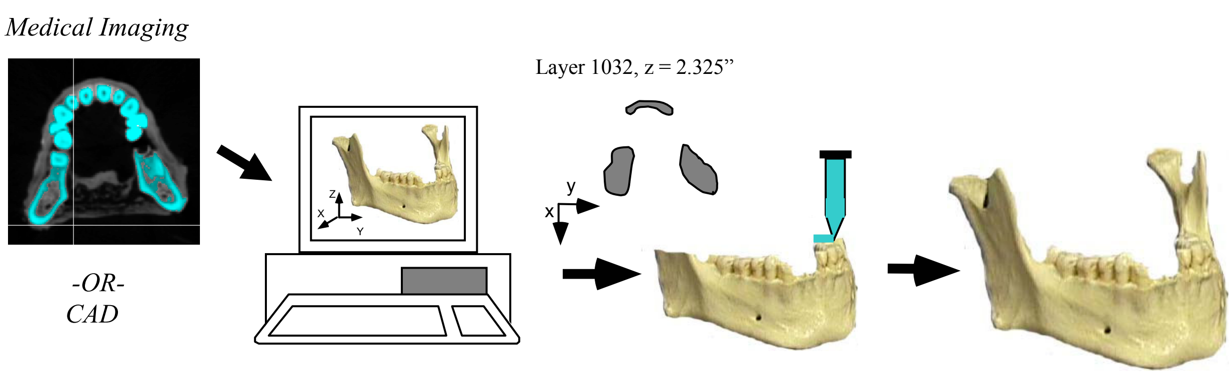

Figure 1. The Rapid Prototyping process.

Engineering 270: ***Applications of CAD and RP for Biomedical Engineering***

The enormous potential of being able to scan existing objects, including complex organic features, modify them or create new designs using CAD technology, and “print” a functional part is self-evident to anyone who has seen the equipment in operation. We have found that RP holds extraordinary fascination to students and industrial visitors of all backgrounds, capturing the imagination and providing a strong attraction into the fields of science, engineering and technology. Rapid Prototyping provides an attractive environment for multi-disciplinary activities and projects, crossing traditional engineering and science boundaries. The General Engineering Program at California Polytechnic State University has used this technology as the focus for a four-unit, one-quarter introductory design experience for its freshmen students. The course is centered around a hands-on, project-based approach to product development. Teams of students are exposed to introductory engineering communications and to basic design through the vehicle of Rapid Prototyping. The students develop competencies over an eleven-week quarter, which allow them to produce prototypes of solutions to design challenges. The class strengthens teaming and communication skills and exposes students to a solids-modeling utility, *Inventor,* which directly integrates to the RPT system used in the lab. Industry sponsors partner with faculty to provide and define challenges for students, to provide intellectual support and a sounding board for students and to provide financial resources necessary to address challenges in a real way. The class provides an excellent segue for subsequent design based courses.

By the Numbers

The General Engineering Program at Cal Poly is one of twelve engineering programs in the College. The General Engineering Program is the sixth largest program in the college, with three-hundred students. It admits sixty to eighty new students each year. The largest single concentration in the program is Biomedical Engineering – which makes up roughly half the student population. Each General Engineering student takes Engineering 270 in either the Winter or the Spring quarter, two lecture sections and three laboratory sections are offered each year. The course is taught by a tenured faculty member, while the laboratory is taught by a long-term lecturer, aided by a graduate assistant. In addition to the personnel costs, consumables for each of the lab sections costs one-thousand seven hundred dollars.

Figure 2. Z-Corporation Z310 “3D Printer” (L) and 3D Systems Thermojet (R) are available for lab projects.

Laboratory Experience

Hands-on projects are a critical part of the ENGR 270 learning environment. Three hours of lectures per week provide the required background in both the "big picture" concepts of modern product development and the special needs of products in the Biomedical Engineering industry, as well as a basic tool kit of *materials & manufacturing processes*, *use of CAD in design*, *problem solving and good design practices*, *technical communication*, and introductory *project planning and management*. Three hours per week of laboratory time following the same topical sequence is where the theory is put into practice. In early lab sessions, students learn the basics of CAD design, operation of RP equipment, and casting techniques. They are then supported by instructors as they prepare their own designs, both individually and in self-selected teams of four students. Two rapid prototyping machines are available for student use (Fig. 2), as well as facilities for solid CAD modeling, plaster and rubber casting, and plastic and metal molding. In the first four weeks of laboratory exercises, students have the ability to go from "art-to-part" for simple designs, and turn their effort to the higher-level goals of integrated product design.

Industry Participation

A second, critical component of the class is a high level of industry participation. Representatives from local companies involved in biomedical engineering are invited to the class early in the quarter to 1) introduce students to their products and product development challenges and 2) provide challenges to the student teams. These industrial challenges are both open-ended, which removes the student from the textbook environment, and "real-world", which provides excitement to the term projects that the student teams will prepare. In the ENGR 270 course, the results of the projects are somewhat conceptual and require only a rudimentary analysis; in the follow-on course, ENGR 440, the industrial challenges are generally sponsored projects, and the results are of professional quality and delivered to the sponsoring company as end products. The ENGR 270 project topics thus serve as the seed for further sponsored research projects. Participating companies also underwrite the material costs for the laboratory, and provide any special materials or software. By fostering strong industry participation early in the curriculum sequence, students establish a continuing relationship which often segues into CO-OP / Internship positions, T.A. positions as an upper division student, or undergraduate research positions for follow-on industry sponsored projects.

Case Study: Accurate Heart Model

The impact of this class on individual students can best be illustrated by an example from our first trial experience. A typical case involves a Biomechanical Engineering student with no previous research experience, and pre-class survey results illustrating her belief that she had below-average aptitude for computer use and independent learning. The industrial challenge offered to her team came from a pacemaker manufacturer: *create both an accurate CAD model and a mechanically-accurate physical model of the human heart to be used in the development of pacemakers*. Background information was presented during lecture sections detailing previous attempts to use Rapid Prototyping combined with medical imaging to produce CAD and physical

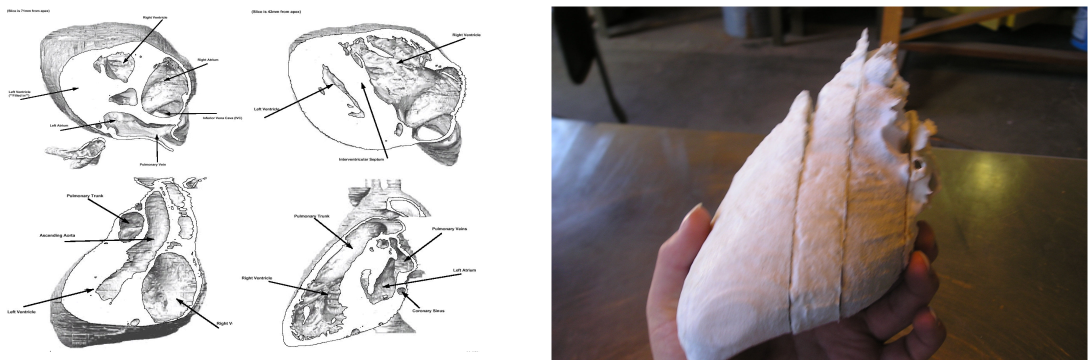

Figure 3. Left: CAD file of Heart. Right: Rubber heart model (expendable pattern produced on 3D System Printer).

(plastic) models of bones. Because the heart is soft tissue and thus more difficult to differentiate, and because the final model needed to be in a flexible rubber, this was an extremely challenging problem. Solving this challenge required the team to perform library research, hold discussions with faculty advisors, and solicit phone/e-mail correspondence with scientists and engineers at the sponsoring company. The team ultimately developed a method to use existing software to create detailed, accurate CAD files of the exterior and interior of the heart, as well as use modified rubber casting techniques to create a detailed physical model. By working as a key contributor to this team, the student in question increased her confidence dramatically, as evident by her continuing interest in further research and the potential for graduate studies. The topics she learned from her experience include the scientific method, product development, anatomy, physiology of the heart, biomaterials, medical imaging, use of specialized software (3 types), project management, technical communication, advanced manufacturing, and Rapid Prototyping. Note that Rapid Prototyping is only a small part of her acquired skills, but it provided the core of an extremely complex problem requiring a multidisciplinary effort.

Linkage to Problem-Based Learning

This class is a successful application of Problem-Based Learning (PBL) to engineering education. PBL has been defined as "learning which results from the process of working towards the understanding of, or resolution of, a problem."[3] PBL has been an extremely successful model for medical education: over 80% of medical schools currently use some form of Problem-Based Learning[4]. Although primarily applied to the biological sciences to date, PBL is an appropriate methodology for technology education[5]; our experiences with using Rapid Prototyping in a Problem-Based Learning environment confirm this. The outcomes of programs applying Problem-Based Learning have been extensively evaluated in educational literature[3-8]. The impact on students under PBL closely match the program outcomes specified by the ABET Engineering Criteria 2000, which require that students have the ability to *apply knowledge, work in multi-disciplinary teams, communicate effectively, and engage in life-long learning*.[5]

PBL begins by presenting a challenging, realistic problem to a small group of students. The group defines or redefines the problem and analyzes it systematically. The concepts required to solve the problem are then agreed upon, and group members assign themselves specific tasks to acquire that knowledge *on the basis of what needs to be known to solve the problem*.[3] Knowledge acquired must be shared among group members, then integrated with existing information to develop possible solutions to the problem. This process is iterated until a satisfactory resolution to the problem is reached. Throughout the process, an educator is present to assist as a *facilitator* rather than as a primary source of knowledge.[6] It has been shown that under this model, students acquire skills essential to continue self-directed learning, rather than trying to remember information that has varying levels of relevancy.[3] PBL-educated students have a more holistic approach to their subject, more readily integrate new information, adapt to change, and work well as members of a team.[3]

For PBL to be successful, certain requirements must be met. The first requirement is that faculty relinquish their traditional roles and develop new skills[7], taking on the role of facilitator. This facilitator is not necessarily a subject expert, but must be provided with sufficient resources and training to assist students in their search for solutions to the problem. From a pragmatic point of view, this will require initial training and continued access to a resource repository. The second requirement is that students be able to work in teams and have access to a wide network of resources. PBL has been shown to work well with learning at a distance[8] if the proper tools are in place, thus the teams and resources can be physically separated. If executed properly, PBL can be a powerful tool to meet the goals of future engineering education: moving the learning experience away from traditional lectures to include a significant level of active learning approaches, facilitating cooperative learning, the production of life-long learners, and the flexibility to include various learning styles.

The introductory design class has proven to be an attention getting retention tool that enables us to build strong connections to industry at an early stage in the curriculum. The course reflects the unique strengths of Cal Poly Engineering and has allowed us to expose students to timeless principles with timely vehicles.

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