AC 2007-860: OVERCOMING THE HURDLES ASSOCIATED WITH INDUSTRY SPONSORSHIP OF MULTIDISCIPLINARY, PROJECT-BASED LEARNING

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Overcoming the Hurdles Associated with Industry Sponsorship of Multidisciplinary, Project-Based Learning

Introduction

As engineering education at the undergraduate level continues to evolve, the support structure required for techniques such as Problem-Based Learning (PBL) is expanding to include not only the Department, College, and University levels, but also significant commitments from industrial partners. Through our experience in developing an Industry/University Consortium for biomedical device companies, we believe that industry provides an enabling means for framing Problem-Based Learning within a *Multidisciplinary, Project-Based* context that exposes engineering students, working in teams across multiple disciplines, to meaningful, real-world challenges. Industry provides the project topics and technical mentors, while projects are self-selected by students based upon a match with their background skills and educational goals. While the benefits are clear, there are a number of challenges in establishing and maintaining the deep level of required industrial interaction (which goes far beyond the traditional dollar-based definition of "sponsorship"). This paper discusses the hurdles that we have overcome, including Intellectual Property ownership policies, developing an infrastructure that allows for simultaneous work on the confidential projects of competing companies, buy-in from faculty in multiple departments, and the critical need for champions in the university and at each company. The paper concludes with a case study that illustrates the typical project-based learning "pipeline" in this model, whereby an engineering student forms an expanding relationship with a company and a multidisciplinary team through early, simple projects, progressing through an on-site industrial CO-OP and culminating with a team Senior Project or Masters Thesis.

Problem-Based Learning within a Multidisciplinary, Industrial Project-Based Context

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. As part of our newly-created Biomedical & General Engineering Department, it was our goal to implement Problem Based Learning (PBL) within a larger, industry project-based context. Based on our experience with industry as a key partner in establishing a new program and department, we approached industry sponsorship from a broader perspective than the traditional dollar-based definition. We see industry as providing an enabling set of resources for a growing curricular program: a source of truly multidisciplinary project topics, technical mentors, and supporting infrastructure that expose engineering students, working in teams across multiple disciplines, to meaningful, real-world challenges.

PBL has been defined as "learning which results from the process of working towards the understanding of, or resolution of, a problem."[1] PBL has been an extremely successful model for medical education: over 80% of medical schools currently use some form of Problem-Based Learning[2]. Although primarily applied to the biological sciences to date, PBL is an appropriate methodology for technology education[3]; our experiences with multidisciplinary student teams working on industry-provided challenges in a Problem-Based Learning environment confirm this. 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*.[1] 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.[4] 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.[1] The outcomes of programs applying Problem-Based Learning have been extensively evaluated in educational literature[1-6]. 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.[1]

For PBL to be successful certain requirements must be met; we have found that a commercial product development environment is a natural fit to a major subset of these requirements. Companies that develop technology-based products, such as medical devices, are of particular value since creation of these products inherently involves multidisciplinary teams. The ideal environment is "CO-OP Plus", where students are immersed in an industry environment working on challenging real-world problems under the mentorship of a practicing engineer (traditional CO-OP), ideally in a multidisciplinary team, with an academic mentor and an open-ended topic that can lead to individualized extra study (the "Plus").

Industry Sponsorship – One Piece of the Puzzle

If executed properly, PBL can be a powerful tool to meet the goals of future engineering education. As engineering education at the undergraduate level continues to evolve, the support structure required for techniques such as Problem-Based Learning is expanding to include not only the Department, College, and University levels, but also significant commitments from industrial partners. It is our belief that an on-site industry infrastructure that provides commercial challenges, environment/culture, mentorship, and advanced engineering tools to students for facilitated, self-directed exploration is an ideal means to achieve true multidisciplinary PBL. This type of interaction, however, requires a significant shift in thinking by industry, extending far beyond the traditional dollar-based definition of "sponsorship". There are a number of challenges in establishing and maintaining the deep level of required industrial interaction, which must be a true partnership with a long-term perspective from both industry and academia.

From an industry perspective, universities often impose fundamental challenges to identifying, requesting, tracking, and funding multidisciplinary projects. For example, at Cal Poly, Senior Project topics have historically been single discipline and kept limited in scope, because of the difficulties involved in working with remote teams and/or multiple advisors. Projects with the potential for high-impact often are not identified by industry as candidates for Sr. Projects, because of a lack of exchange opportunities. Industry simply does not know the capabilities at Cal Poly, and Cal Poly faculty do not know enough about current specific industrial challenges to suggest project opportunities. The current mechanism whereby industry pays for projects on a case-by-case basis is cumbersome, requires significant overhead, and does not fit well with most company's internal requisition cycles. Faculty advisors are identified in an ad-hoc manner, and there is a lack of accountability for student deliverables. The lack of continuity between classes of students as they graduate limits the length of current candidate projects, and even more damaging, the perceived (and real) learning curve is viewed as a burden by industry mentors. Finally, intellectual property ownership policies are often so constraining that, rather than working with a university on a simple student project, a company will choose not to bother.

Many of the abovementioned problems can be classified as problems of *infrastructure.* Developing the physical facilities and streamlined processes that allow participants from both industry and academia to participate in collaborative activities is critical to a successful partnership. Developing an infrastructure that allows for simultaneous work on the confidential projects of competing companies, provides a single point of access for matching students, faculty, and industry needs, and serves as a model that can be promoted by academic management is key to obtaining the necessary buy-in from faculty in multiple departments, technical managers and management champions at each company, and a pool of motivated, talented students who compete for opportunities. It is also, in our experience, the key to a continued funding commitment which can survive the departure of any critical individual on either side of the partnership.

Our Solution: ***MEDITEC***

MEDITEC (*Medical Engineering Development and Integrated Technology Enhancement Consortium*) is an industry/academic partnership that matches multidisciplinary teams of undergraduate and masters-level engineering students with the project needs of biomedical device developers and provides the firewalled infrastructure to simultaneously work on the confidential projects of competing companies. Industry provides the project topics and technical mentors, while projects are self-selected by students based upon a match with their background skills and educational goals. Reconfigurable project space, with physical isolation between company projects, is provided on campus. This physical laboratory serves as the focus of continuity for more complex, longer-term, multi-disciplinary projects. Older students who are returning from CO-OPs at a Consortium company serve as sources of corporate culture and mentorship, while academic advisors from multiple disciplines round out the advising trio and ensure that balanced learning objectives are met. Governance of the Consortium is broadly defined by the following:

1. *Cal Poly actively solicits interesting industrial applied research projects for individual and student teams at both the undergraduate and graduate level.*
2. *The MEDITEC Consortium provides a mechanism to match the project needs of industrial participants with the interests and capabilities of Cal Poly students.*
3. *Industrial funding of the Consortium is in the form of an annual donation to the Biomedical and General Engineering Department. Funds are used to provide student stipends, project related expenses (consumables, etc.), and general MEDITEC laboratory infrastructure.*

4. *Industrial participants will provide Cal Poly with abstracts for project topics; pre-screened students, after signing a NDA, will be able to view and select projects. The Consortium Director will facilitate the matching process to ensure even distribution of students over participating companies. Timing/deliverables/etc. will be agreed upon between the student and the appropriate company representative, who will act as technical advisor. Cal Poly faculty members will act as academic advisors.*
5. *Participation in MEDITEC also includes a seat on the Consortium Advisory Board; the Advisory Board will receive periodic operational updates and suggest spending priorities for all aspects of Consortium operation including longer-term projects, infrastructure, etc.*
6. *The Non-Disclosure and Intellectual Property Agreement shall be the binding document for IP issues. Cal Poly will maintain IP protection through the physical separation of industrial projects from the general student/faculty population and from other companies participating in MEDITEC.*

We are currently in our second year of Consortium operation, after an initial pilot program which demonstrated clear benefits to both our initial industrial partner and to Cal Poly. Success is only possible with a long-term commitment, so buy-in by industrial partners must be more than superficial. Demonstrated *company* benefits include:

- Additional resource for company engineering projects.
- Support training goals of recruiting by providing real-world challenges to potential employees.
- More work done for less cost.
- Allow company to utilize students to supplement heavy peak loads.
- Identify and recruit promising candidates early.
- Head start on training, reduced training requirements by providing experiences that immerse students in company challenges while still in school.

Project Initiation

Project topics are solicited with a Call for Projects to the company's engineering staff, and span the spectrum from single discipline, short-duration projects through multidisciplinary senior or Masters-level projects. All projects involve engineering design; care is taken to select meaningful projects from engineering areas of need. An example would be tool design for a mechanical development test effort or sustaining engineering on any of many projects in software, hardware or research. Company engineers see the selection of a project topic as a real benefit, and strive to define engaging projects that will be selected by students. Part of the project form defines the Abstract of the project. Project skill levels are specified by the project manager/mentor and it is clear to the student what level is necessary. For all levels and areas of engineering interdisciplinary need, tasks are defined as D – desirable, or R – required (Figure 1). Abstracts are collected into a database, with the Consortium Director on the university side serving as a facilitator for matches between students and projects. After signing a non-disclosure agreement, students are invited to explore the database and form teams to complete projects. Minimal guidance is given regarding how to form teams, as leadership is a key skill that is

ID	Title	Department	level
1001	XXXX Aarrhythmias as input for ICD/Pacing tests	BMED	M
1002	XXXX Comorbidities Study	BMED	
1003	Heart Disease Progression Study	BMED	M
1004	XXXX Model Arrhythmias	BMED	
1005	Programmer XXXX GUI Project	CE	
1006	Unified Test System - Gateway and SIM Automation	CE,CS	
1007	Convert XXXXX-based files into XXXX		
1008	Test Constructor Project	CE,CS	
1009	Lead flex fatigue tester	BMED, IME	
1010	Mechanical Properties of the Heart	BMED	M
1011	Automated Medical Adhesive Dispenser	ME	S
1012	Visual EMF Editor Requirements & Design Feasibility	CS	S
1013	Screen Capture and Object Recognition	CE	S
1014	XXXX Assessment of Carbon Biocompatibility	MATE	M
1015	Adhesives for XXXX Material	MATE	M
1016	XXXX Assessment of Copolymer	MATE	M
1017	Adhesives Aging Study	BMED	S
1018	Peeling Tool	ME	S
1019	Parsing Delimited Data		
1020	XXXX Programmer Script Design Optimization	CS, CPE	
1021	XXXX Programmer Environment Stress Tester - Automated Scripts	CS, CPE	
1022	Test Development Environment Scripts Editor	CS, CPE	
1023	XXXX Testbed - Data Storage	BMED	M
1024	Lead's Testbed - Chest Cavity	CE	
1025	MEDITEC Database Development	CS	S
1026	Internet Control of Computer Peripherals	CS	S
1027	Heart Motion Simulation	BMED	M
1028	LED Lead Instrumentation	BMED	M
1029	Data Analysis		
1030	Delivery System Slitter	ME	S
1031	Research Data Analysis	BMED	M
1032	Tachycardia Therapy Simulator	EE	M
1033	Unity EMT Motion Controller	CE	
1034	Unity Exercise Compliance Algorithm Prototype Development	CS	

Computer Science (CS) / Computer Engineering (CE) / Software Engineering (SE) *Level: R=Required, D=Desired*			
Item	**Skill**	**Level**	**Details**
C1	Test Automation	R	Experience in Automation tool / scripting / Test execution
C2	Test Design (For Manual / Auto)	R	Knowledge of designing tests, approaches for execution
C3a	Eclipse - from User perspective (3.x, 4.x)	D	Work experience with Eclipse / Basic knowledge of Eclipse.
C3b	Plugins		Knowledge of Eclipse and various plugins in Eclipse (e.g. Clearcase)
C3c	EMF (Eclipse Modeling Framework)		Basic knowledge of EMF (EMF is a powerful framework and code generation facility for building Java applications based on simple model definitions.
C4	UCM (Unified Change Management)		Basic knowledge of UCM
C5	Linux	D	Basic commands, search pattern, navigation, editing, file i/o, paths etc.
C6	SQA	D	Knowledge of software processes, SDLC
C7	UML	D	Understanding of UML & it's concepts
C8	Use Case Requirement Methodology	D	Understanding of requirements in Use Case form.
C9	Java		Work experience in Java / Basic knowledge of Java.
C10	RDBMS (Oracle / MS Sequel / My Sequel)		Not DBA. Basic knowledge of SQL, basic definitions of RDBMS
C11	DOORS		Basic knowledge of using Requirement management tool DOORS
C12	Standard Editing Methodologies	R	Familiarity with generic text/table editing, tabs, etc
C13	HTML and XML	R	Working knowledge of HTML and XML
C14	Hardware		Experience in testing products which consist of software and custom hardware components

Figure 1. Example project topic database listing and skill set list

nurtured through this program. Projects are self-selected by the students, and companies do not have input to prioritization – it is understood by the companies that students who are excited about a particular topic will perform at a higher level. An expiration date is associated with each project, such that company managers will know to seek alternate means of accomplishing a project if it has not been picked up by a certain date.

Intellectual Property and Laboratory Infrastructure

Establishing specific Intellectual Property ownership policies for MEDITEC was a significant milestone. Simply put, the IP from all projects proposed by a company, funded by the company, using equipment provided by the company, with university mentors in a purely advisory role, should be the property of the company. IP belonging to the company eliminates the single biggest barrier to establishing a fruitful relationship. Note that this is complementary rather than conflicting with the IP policies of most progressive universities; in cases where there will be a larger faculty presence, specialized university equipment, or expertise, a separate contract will be established, governed by standard university IP policy. For student-based MEDITEC projects, however, IP ownership is squarely in the hands of the topic provider.

The physical embodiment of the Consortium is dedicated campus space in a donated building that serves as a flexible, modular, expandable laboratory providing general product development tools as well as space for "loaner" equipment provided by the companies to support a specific project. Building a laboratory such as this at a State University is generally an expensive and daunting experience, but this lab has been successfully assembled through a combination of Consortium funds, company-donated equipment, creative arrangements with vendors, cooperation between engineering departments to purchase shared resources, and equipment that was purchased from student fee funds managed by the students themselves. Having a longer-term vision allows the laboratory to be pieced together one component at a time, while carefully selecting each new component such that it adds increased, general-purpose functionality while fitting within the integrated whole. Criteria for selection of equipment includes, in order of importance, low acquisition cost, durability, general applicability as a stand-alone engineering tool, low operations cost, and expected life of technology to avoid obsolescence. Nominally 50-70% of resources in use at any given time is specialized equipment on loan by a company to support a given project (e.g. a heart simulator), or purchased by the company on behalf of the project.

Project Monitoring & Mentoring

A technical manager at the Consortium company serves as the primary mentor and customer for a given project. Cal Poly is generally a 3 hour drive away from our member companies, so students typically travel for a kickoff meeting and 1-2 additional face-face meetings during the period of performance. Tele- and videoconferencing facilities are available, but we find that most communication is via email and shared web space. Milestones are defined to establish the delivery progress. Projects need not be structured to correspond to a university semester or quarter, but can be partially completed and assigned to another group of students if necessary. On the university side, this has required a paradigm shift that students in many projects are measured on progress, and not necessarily completion of the effort assigned.

Student success is important to participating companies for several reasons. First, student results help the company do their job more effectively. Second, it helps to further establish the industry-university relationship, which becomes increasingly valuable as recruiting ramps up. Third, it gives insight into a company's own business practices and interests and possibly helps students decide on a career path. When students succeed, the company succeeds. To facilitate a successful process, communication is emphasized. Weekly status reports showing progress, problems and questions needing answers are required to be submitted in written form. Students are accountable for milestones and their estimated completion dates. Domain knowledge and a company's specific engineering process are provided by technical mentors. For example, our pilot corporation stresses "six pillars" of competencies for university students:

- Quality
- Innovation
- Teamwork
- Communication and interpersonal effectiveness
- Personal commitment
- Continuous Improvement

Project Continuity

The MEDITEC program is geared towards undergraduate and Masters-level multidisciplinary projects, rather than extended fundamental research performed by faculty/post-docs/PhD students. Because of this, project continuity becomes a key challenge. The physical infrastructure, overlapping student teams within a given project topic, and students returning from Consortium company CO-OPs are critical to maintain long term process and culture continuity even though the typical team cycle time is on the order of 4-7 months. Returning CO-OPs are given the title University Associate (UA), and can complete an unfinished CO-OP project while on campus in Consortium facilities. This effectively extends the CO-OP period beyond 6-mo., which is attractive to both the company and students. Additionally, these UAs perform individually-directed collaborative research, mentoring, and training of younger students. They become the cultural face of Consortium companies on campus. They are paid for this activity while in school. This helps the more senior students take leadership roles and teach company domain issues and engineering process. It puts graduating students in a continued role of responsibility, and keeps former CO-Ops in touch with sponsoring companies on a regular basis. We have found that University Associates are likely to use this opportunity to segue from undergraduate into graduate studies. This combination of opportunities can create up to two-year package of industrial training and experience before students begin full time employment:

Early Design Classes → CO-OP → Funded Sr. Project → Full Time Employment
→ Distance Learning Masters Degree

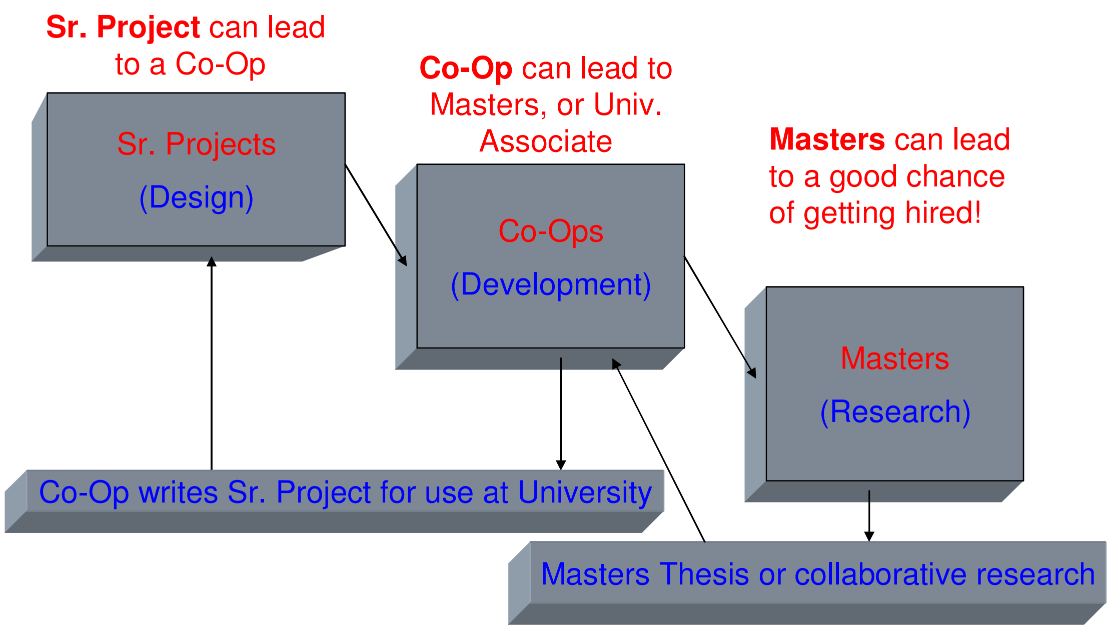


Figure 2. Combination of opportunities can create up to two-year package of industrial experience while still in school.

Results of Pilot Program (In the words of our pilot corporation)

Without being specific about project results, it can be said that projects are almost always more successful than we could have imagined from an industry perspective. We get to see much more than just a project written on a resume and have learned to emphasize and recognize our pillars for success for engineers. We get to see innovation, teamwork, quality, and continuous improvement patterns throughout the projects. Of the 38 projects put in the queue in mid 2005:

- 19 student-selected projects were attempted
- 17 projects were completed to a high level of success
- Projects involved multidisciplinary teams from BMED, ME, EE, CS, and IME
- Several projects have been converted to Masters thesis efforts
- 4 Students continue their work on campus as University Associates

The first success measure is that we have so many projects involved. It is obvious that our engineers value the industry/university relationship in many areas. This is not a small measure. It takes time to oversee effort like this from a development standpoint and university perspective. Our combined teams feel so strongly of the value of Senior Projects, CO-OPs and joint learning opportunity that all are placed at high value. In an environment where competition and technology leadership are on everyone's minds, the ABET requirements of the colleges of engineering make a case of long term benefits of great value to all parties.

Just about all our engineering departments want more projects submitted to the MEDITEC program. That is the test of value one can not deny. This effort is instrumental in starting our process of university relations. A whole "pipeline" of activity is started through this process. It results in student contact and awareness by our recruiting staff of the best possible candidates for our demanding engineering needs.

Keys to Success

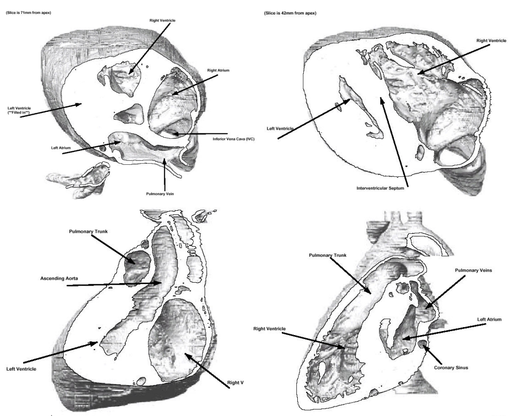
In our experience, industry sponsorship to the level of commitment required to achieve true multidisciplinary Project-Based Learning requires:

- An Intellectual Property policy that is narrow in focus, but weighted heavily toward corporate ownership.
- Development of an infrastructure that allows for simultaneous work on the confidential projects of competing companies.
- Buy-in from faculty in multiple departments.
- Champions in the university and at each company.

The earlier an industrial partner starts involving itself in the university environment, the better the results. Our pilot corporation now coordinates multidisciplinary projects (MEDITEC), Senior Projects, Co-Ops, Masters Thesis projects, Distance Learning, and Clinical Classes / Symposiums, all to the benefit to both organizations. Preliminary results suggest that this model 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. In the words of our corporate champion, "The more we work together, the better it gets."

Case Study: Accurate Heart Model

The impact of this program 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 (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. She accepted a CO-OP at the Consortium company, and is currently planning to continue her studies, bringing her CO-OP project back to campus to extend the work in the MEDITEC program as part of a Masters Thesis. 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 the laboratory equipment is only a small part of her acquired skills, but it provided the core of an extremely complex problem requiring a multidisciplinary effort.



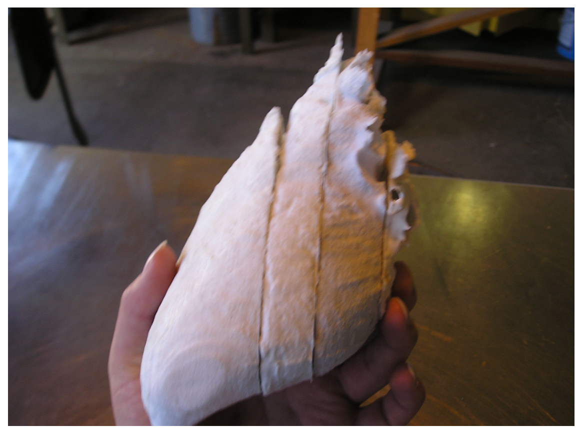


Figure 3. Left: CAD file of Heart. Right: Rubber heart model (expendable pattern produced on 3D Printer).

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