AC 2007-861: MEDITEC: AN INDUSTRY/ACADEMIC PARTNERSHIP TO ENABLE MULTIDISCIPLINARY, PROJECT-BASED LEARNING IN BIOMEDICAL ENGINEERING

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MEDITEC: An Industry/Academic Partnership to Enable Multidisciplinary, Project-Based Learning in Biomedical Engineering

Introduction

MEDITEC (Medical Engineering Development and Integrated Technology Enhancement Consortium) is an industry/academic partnership at California Polytechnic State University 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. The *Project-Based* context provided by the Consortium structure exposes engineering students 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. The educators (both academic and industrial) are present to assist as *facilitators* rather than as a primary source of knowledge, and students acquire skills essential to continue self-directed learning. This paper focuses on our experience during a recently completed pilot program, where projects have included creating soft tissue models for medical device development, automation of complex manufacturing processes, and development of prototype surgical tools. Successes and lessons learned will be discussed from both academic and industry perspectives. 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. 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

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 the Biomedical Device 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.

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").

If executed properly, PBL can be a powerful tool to meet the goals of future biomedical 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.

MEDITEC

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.

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. 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 the confidential projects of competing companies, 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. 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.

Laboratory Infrastructure & Typical Projects

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 vendor arrangements, cooperation between engineering departments to purchase shared resources, and equipment 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 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. Projects have included creating soft tissue models for medical device development, automation of complex manufacturing processes, and development of prototype surgical tools. Other examples include tools 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 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. Specific project topics from our pilot Consortium member (developer of Cardiac Rhythm Management Devices) include:

- Literature Assessments: Heart Mechanical Properties, Carbon Nanotube Biocompatibility
- Database Development: MS Access, parsing delimited data on legacy systems
- Automation: Automated Medical Adhesive Dispenser, Motion Controller, Internet Control of Computer Peripherals
- Statistics & Research Data Analysis: Evaluating research data for trends, etc.
- Materials Evaluation: Cytotoxicity / Aging Study for new material system
- Development of Surgical Tools: Solid Modeling + Design & Prototyping
- Physical Simulation Systems: Heart Motion Simulation, Therapy Simulator, Lead's Testbed, Computer Simulation of Arrhythmia Signals

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.

Projects are truly multidisciplinary, with BMED students working in teams with other engineering disciplines, including Mechanical, Electrical, Industrial, and Computer Science/Computer Engineering. Because the MEDITEC program is specifically geared towards the educational needs of undergraduate and Masters-level projects, rather than extended fundamental research performed by faculty/post-docs/PhD students, 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

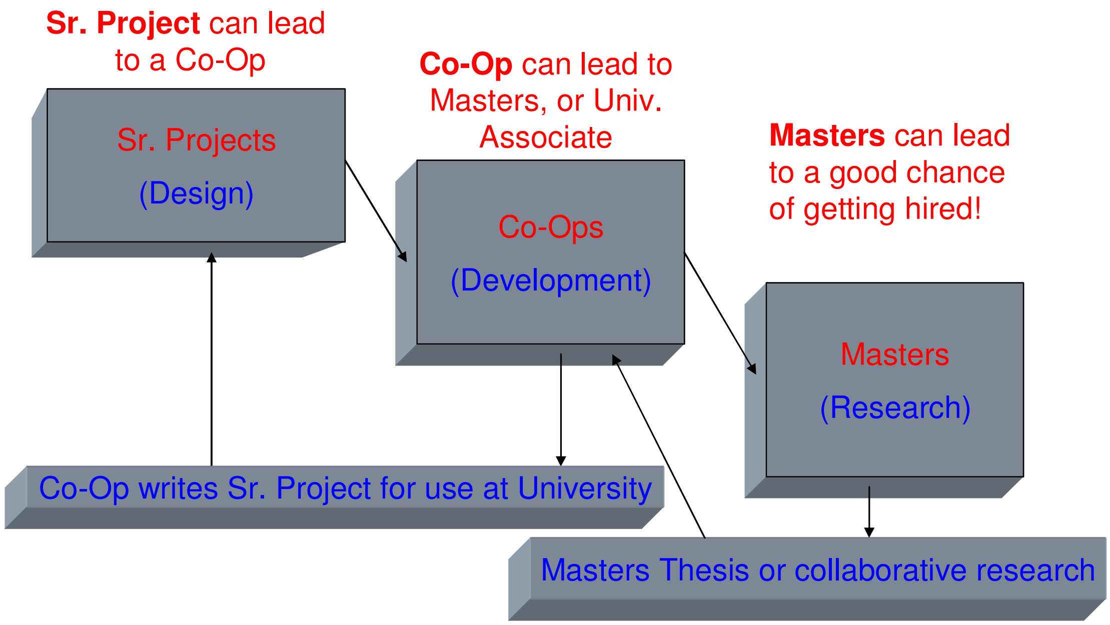

Figure 2. Combination of opportunities can create up to two-year package of industrial experience while still in school.

Because it streamlines access to motivated students, MEDITEC offers clear benefits to companies. The university benefits, too, as the MEDITEC infrastructure extends beyond a simple "project shop" and provides an on-campus theme for learning, through hands-on experience, key aspects of Biology, Design, Communication, Manufacturing, Problem Solving, and Materials. The philosophy behind integrating the MEDITEC infrastructure into the curriculum as early as sophomore-level classes is that engineering tools and phenomena are used long before they are completely understood. By immersing themselves in tackling biomedical industry challenges with no clear solutions using state-of-the-art equipment, it is our experience that students become more willing as they continue their educational career to approach comprehensive problems seeking holistic solutions. The ideal outcome of the MEDITEC infrastructure, then, is to provide an industry-focused laboratory environment that supports increasingly sophisticated levels of engineering exploration as the student matures.

Integration of MEDITEC Projects into the Curriculum

In addition to individual and team Senior Projects, Masters Theses, and independent study projects, a key component of the Consortium is that biomedical industry needs are addressed in the classroom, with industry mentors serving as co-instructors, providing topics and continuing technical guidance throughout the quarter. Design exposure for Biomedical and General Engineering students starts in the second quarter of the freshman year. MEDITEC projects are currently support this introduction to design, as well as focused-topic sophomore/junior-level CAD/modeling/simulation classes, and a two-quarter senior design sequence.

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 Rapid Prototyping (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. We have used this technology, applied to solving the problems of biomedical device manufacturers, as the focus for a four-unit, one-quarter introductory design experience for 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 allows them to produce prototypes of solutions to design challenges provided by Consortium members. The class strengthens teaming and communication skills. Industry mentors, typically a technical manager with an interesting, non-critical-path project goal, partner with faculty to provide and define challenges for students, to provide technical guidance during the quarter, and to act as the customer during requirements development and project presentation stages. The class provides and excellent segue for subsequent design-based courses.

3 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*. 3 hours per week of laboratory time following the same topical sequence is where the theory is put into practice.

BMED 455/456: Biomedical Engineering Design I & II

In the ENGR 270 course, the results of the projects remain at a fairly high level; in subsequent senior design courses, BMED 455 & 456, the design problems are more challenging Consortium projects, and the results are of professional quality and delivered to the sponsoring company as end products. Consortium challenges often require incorporating organic shapes and biological data into product designs – designs that must work intimately with the body both physically and functionally (e.g. surgical tools such as a steerable catheter).

Similar to ENGR 270, 3 hours of lab parallel and supplement 3 hours of lecture per week. In early lab sessions, students gain the necessary competency in advanced CAD design, operation of modern prototyping equipment, and casting/molding techniques. They are then supported by instructors and industry mentors as they prepare their designs in self-selected teams of four students. By the 2nd half of the quarter, the formal laboratory training is complete and the equipment is made available for individually-directed student use. Within the first four weeks of laboratory exercises, students have the ability to go from "art-to-part" for simple CAD designs, and can turn their attention to the higher-level goals of integrated product design (Figure 3).

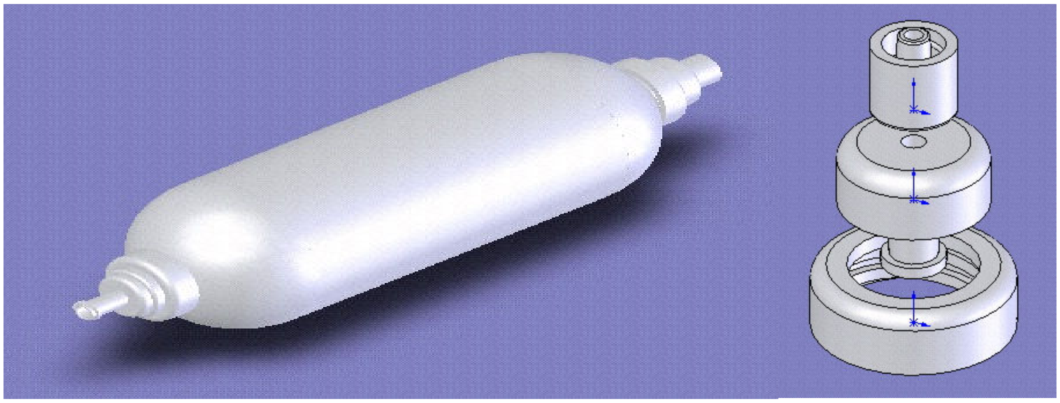

Figure 3. Pain Pump developed as part of BMED 455.

<u>BMED 430: Simulation and Modeling for Biomedical Engineering</u>

This year, MEDITEC projects are being introduced into an existing course on the topic of simulation & modeling for Biomedical Engineering. Finite Element Analysis (FEA) of anisotropic materials and organic geometries from CT data is being explored by the students, using advanced FEA packages such as ANSYS, Abaqus, and LS Dyna. Consortium members have great interest in this type of modeling for applied product development efforts. Current classroom activities involve modeling mechanical properties of tissue such as bone. In one such simulation, students examined how a total knee replacement effects the stress distribution on the bone tissue (Figure 4, Left). We are moving toward simulation of soft tissue, such as a heart model obtained from MRI or optical images (Figure 4, Right). Simulations such as the knee replacement enable the students to work on problems that are technically challenging, have open-ended solutions, and are of direct interest to industry to develop product designs that ultimately enable medical devices to better integrate with the host.

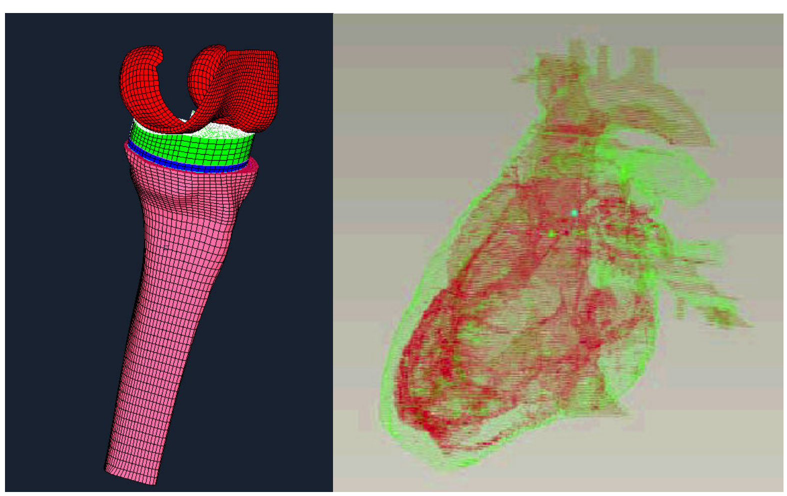

Figure 4. (L) Complex FEA of knee implant, including anisotropic properties of femur. (R) FEA mesh for heart.

A critical component of the classes described above is a high level of industry participation. In both 270 and 455/456, representatives from MEDITEC companies 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. MEDITEC underwrites the material costs for the laboratories, and provides funding for acquisition of additional special materials or software. These industrial project topics often serve as the seed for further development as Senior Projects or Master's Theses through the MEDITEC program. A typical pattern is that a student will take ENGR 270, participate in a CO-OP at a Consortium company, and come back to complete Senior Project as part of the MEDITEC program. An increasing trend is that students choose to take advantage of the Cal Poly 4+1 program, extending their industrial project into the foundation for a Master's Thesis. By fostering strong industry participation early in the curriculum sequence, students establish a continuing relationship with a company, which serves them in expanding opportunities throughout their academic career and often serves as the launching point for their professional career.

Lessons Learned and 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.

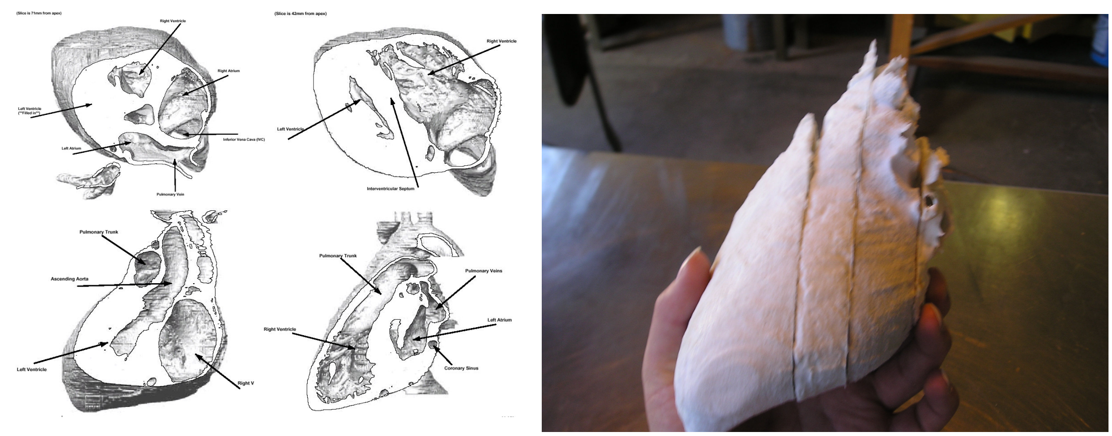

Figure 5. Left: CAD file of Heart. Right: Rubber heart model (expendable pattern produced on 3D Printer).