AC 2010-19: BODY BY DESIGN: A MODEL FOR K-12 OUTREACH IN ENGINEERING EDUCATION

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Abstract

There is a strong need to enhance recruitment and diversity of students in the field of engineering. Outreach to the K-12 sector is key to improving the pipeline of students who wish to pursue an education in engineering. Countless children are interested in engineering technology yet they often lack the mentorship, educational opportunities, or role models necessary to make this a realistic career path. The educational system further narrows the selection of students in engineering as most technologically rich courses are delivered in a sequential manner with no active exercises or connection to the real world. This approach places children who learn in global, sensing, visual, and active modes at a disadvantage and restricts opportunities for diversity. Engineering outreach that provides interactive projects and addresses the spectrum of learning styles can enhance both interest and diversity in engineering. A model for K-12 outreach teaching has been incorporated into an undergraduate engineering course entitled, Structural Aspects of Biomaterials. As part of this course, the undergraduates participate in a semester-long project, entitled “Body by Design,” in collaboration with a children’s museum and a 5th grade elementary science class. At the start of the course, the undergraduates evaluate their own personal learning styles (active vs. reflective; intuitive vs. sensing; sequential vs. global; visual vs. verbal). Students are then matched up in groups of four with balanced learning styles, major, and gender. The undergraduates are simultaneously enrolled in a skills laboratory that provides a framework for oral and written communication, teamwork, and effective teaching styles. Within this framework, the undergraduates are continually surveyed and assessed on the learning outcomes for the course. The objective of the outreach project is to interest more children in the field of engineering. Undergraduate groups are assigned a medical device with the task of teaching a technical concept associated with the medical implant to the K-12 learner using an interactive scientific exhibit that addresses all facets of learning. The benefit is that children experience engineering in an interactive environment that is accessible regardless of learning style. The K-12 learners are assessed using an informal interview process at the museum. This program could be implemented as a model for other engineering outreach projects. The objective of the K-12 outreach project is to interest more children in the field of engineering while strengthening the engineering and communication skill sets of the undergraduates. This outreach project provides a unique opportunity for undergraduate students to demonstrate their grasp of the subject matter while inspiring children to have a renewed interest in math, science and technology and the goal of becoming an engineer.

Motivation for K-12 outreach

Outreach to the K-12 sector is essential for the technological advancement of our society and for diversity enhancement in engineering. Many children are naturally interested in engineering technology but they may not have the mentorship, educational opportunities, or role models needed to pursue this field of study. Further, most technologically rich courses, both at K-12 and undergraduate levels, are taught in a format that favors certain learning styles. Such classes are typically delivered in a sequential manner (derivations of formulas, etc) with little or no active exercises in the classroom, and are often disconnected from societal needs or real world
applications. Students who learn in global, sensing, visual, and active modes are often disadvantaged in the traditional curriculum although they could be first-rate engineers. Moreover, this educational process restricts opportunities for diversity. Engineering outreach that provides interactive projects and addresses the spectrum of learning styles can enhance interest and diversity in engineering.

A Model for K-12 outreach teaching in the undergraduate engineering curriculum

A model for K-12 outreach teaching has been incorporated into an undergraduate engineering course entitled *Structural Aspects of Biomaterials*. This is a multidisciplinary elective course cross-listed between Mechanical Engineering and Bioengineering with an enrollment of about 50 students and an even gender split. As part of this course, the undergraduates participate in a semester-long project, entitled “Body by Design”, in collaboration with a children’s museum and a 5th grade elementary science class. At the start of the course, the undergraduates evaluate their own personal learning styles (active vs. reflective; intuitive vs. sensing; sequential vs. global; visual vs. verbal). Students are then matched up in groups of four with balanced learning styles, major, and gender. The undergraduates are simultaneously enrolled in a skills laboratory as part of the course that provides a framework for oral and written communication, teamwork, and effective teaching styles. The objective of the K-12 outreach project is to interest more children in the field of engineering while strengthening the engineering and communication skill sets of the undergraduates.

There is strong evidence that outreach to the K-12 sector is a vital part of maintaining and improving the numbers of current and potential students who study engineering at the university level. Many children are naturally interested in the technologies they see in everyday life yet they may not have contact with adults who have the expertise to entertain their questions or their learning styles may be in conflict with traditional curriculum formats. For these children, an outreach program can offer exposure to engineering skills such as analysis, development, building and testing through hands-on activities. The benefit of using undergraduates to develop and implement engineering exhibits that addresses all facets of learning is that children experience engineering in an interactive environment that is accessible regardless of learning style. Moreover, exposure to young, diverse role models reinforces the notion that engineering is a career path that is accessible to people regardless of gender or ethnicity.

Introduction to engineering technology at an early age has many benefits including the development of problem-solving skills, an increased motivation to study math and science by demonstrating relevant applications for these disciplines, and an interest in engineering as a career path. The implementation of an engineering outreach project based on service-learning and teamwork concepts in the undergraduate engineering curriculum offers enormous benefit to all participants. The undergraduate students are engaged in an active learning process that develops their communication and collaborative skills while serving society, whereas the elementary grade students gain insight into engineering and applications of technology regardless of their learning style. This outreach service-learning program serves as a model that can be readily implemented in the engineering curriculum.
Course development

Educational studies affirm that traditional lecture-based teaching is not always the best way to impart information to undergraduates and that they profit from a more active role in their own learning.\textsuperscript{6-9} Mooney and Mooney\textsuperscript{7} state “... one learns more completely what one has to teach rather than what one simply hears or reads...” and thus, by involving undergraduates in a service-learning outreach project, they gain a deeper understanding of the subject matter. Furthermore, skills such as teamwork, communication, connection to society and appreciation of diversity are recognized as important abilities that are necessary for all engineers graduating from ABET-accredited programs [10]. With these facts in mind, the K-12 outreach teaching project entitled “\textit{Body by Design}” was developed as a central portion of an upper division technical elective course cross-listed between mechanical engineering and bioengineering.

\textit{Structural Aspects of Biomaterials} has been taught for nearly a decade and in this timeframe, the course has evolved from a survey course to a course with emphasis on project-based learning, interdisciplinary problems, teamwork, and outreach teaching. By the end of the semester, undergraduates are expected to have an ability to design a load-bearing medical device that would meet the criteria for approval by the Food and Drug Administration (FDA). Topics covered in this interdisciplinary course include (i) structure of biological and engineered materials, (ii) biocompatibility; (iii) mechanical behavior of materials, (iv) design methodology, and (v) clinical needs for medical implants in orthopedics, dentistry, soft tissue repair and cardiovascular applications. The course content is summarized in Table 1.

In designing the outreach project, several objectives were kept in mind. First, the project had to demonstrate the students’ knowledge of course content. Since this project is in lieu of a final examination, it was necessary that undergraduate students display a strong understanding of the various technical topics covered in the course. The undergraduates were assessed in their project delivery and teaching methodology by the professor, graduate student instructors, and the science museum education staff on the day of the exhibit. Second, the students were also to demonstrate outreach to the target age group (5\textsuperscript{th} grade). Each project not only had to teach a technical concept associated with a medical device but also had to do this while addressing different learning styles (active, reflective, intuitive, sensing, sequential, global, visual and verbal). Finally, the projects were all conducted in teams selected to balance learning styles, gender, and major. Working in groups provides the undergraduates with the valuable experience of working with their peers to accomplish a common goal.\textsuperscript{11}
### Table 1. Class syllabus for *Structural Aspects of Biomaterials.*

This course covers the structure and mechanical function of load bearing tissues and their replacements. Biocompatibility of biomaterials and host response to structural implants are examined. Quantitative treatment of biomechanical issues and constitutive relationships of materials are covered in order to design implants for structural function. Material selection for load bearing applications including reconstructive surgery, orthopedics, dentistry and cardiology are addressed. Case studies of clinical failures, designs, and material behavior are presented.

#### I. Overview of Biomaterials, Tissues and Regulatory Issues (with embedded case examples)

- Overview of biomaterials used in medical devices
- Review of structural materials: metals, ceramics, polymers, and composites
- Review of structural tissues and constituents: bone, cartilage, vascular tissue, and dental tissues
- Biocompatibility and Sterilization
- Regulatory issues, FDA testing and product development

#### II. Constitutive Behavior and Biomechanical Design Issues (with embedded case examples)

- Elastic behavior, multiaxial loading, time-dependent behavior
- Yield criteria and permanent deformation in devices
- Fracture criteria and design concerns with brittle materials/stress concentrations
- Fatigue: Total life and defect-tolerant philosophies
- Friction, Wear and Lubrication

#### III: Clinical Issues (with embedded case examples)

- Orthopaedics: total joint replacement, soft tissue repair, and spinal implants
- Cardiovascular: catheters, stents, grafts
- Dental: implants, TMJ restoration
- Soft Tissues: reconstruction and augmentation
- Intellectual property: patents, device development, legal and ethical issues

#### Professional Development Lab

- Learning styles, Blooms Taxonomy
- Pedagogy and outreach teaching
- Technical research, writing and presentations
- Team work and peer-review
- Design methodology
**Project development**

Early in the semester, the education specialists from the partnering children’s science museum provide a project kick-off lecture that addresses interactive exhibit design and mechanisms for engaging children. The science center education team serves as consultants to the undergraduates and evaluates the teams’ progress midway through the semester. The projects with medical devices and associated technical concepts are provided to the groups; however the groups have some choice in their selection based on a random drawing of numbers. For the Spring 2009 semester, the overall exhibit was entitled “Body by Design” and this theme is in its third iteration. At the start of the project, the undergraduate groups are assigned a medical device with the task of teaching a technical concept associated with the medical implant to the K-12 learner using an interactive scientific exhibit that addresses all facets of learning. The medical implant/design consideration pairings were developed so that each engineering concept would be taught with a relevant application, as shown in Table 2.

<table>
<thead>
<tr>
<th>Medical Implant Design Consideration Topics</th>
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<tbody>
<tr>
<td><strong>Medical Implant</strong></td>
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<tr>
<td>Stents</td>
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<tr>
<td>Breast implants</td>
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<td>Heart valves</td>
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<tr>
<td>Heart valve replacements</td>
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<tr>
<td>Intervertebral disk</td>
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<td>Total knee arthroplasty</td>
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<td>Total knee replacement</td>
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<tr>
<td>Total joint replacements</td>
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<tr>
<td>Dental implant</td>
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<tr>
<td>Total hip replacement</td>
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<tr>
<td>Hip stem implant fixation</td>
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The course project was highly structured in order to facilitate success of the group work. To this end, various benchmarks were assigned to assist students in developing their project over the course of the semester. These were:

- Personal assessment of learning styles
- A write-up which included the history of the device and the current state-of-the-art configuration
- An exhibit development plan in a specified format
- A two-minute “elevator speech” demonstration for their peers, teachers and science center staff
- Feedback on the project day from the elementary school students and science center staff as well as from course instructor and graduate student instructors
- A write-up which detailed the project development, evaluation and lessons learned
- Team members’ evaluations.

The undergraduate students were asked to think about their exhibits from the point of view of the 5th graders. Each group was asked to develop their learning objectives, explain their “hook” (how they planned to draw the children in), give details about their activities and mechanisms for
addressing the various learning styles, and generate a list of the materials they would need for their exhibit. The science center supplied tables, electrical hookups, basic supplies, as well as limited reimbursement for materials purchased (no more than $50), but students had to utilize their creativity and ingenuity to produce much of their exhibits. Students were mostly unfamiliar with developing a lesson objective. Bloom’s Taxonomy was introduced as a method for developing and evaluating lesson objectives.  

At mid-semester the undergraduates were asked to provide a two-minute elevator speech and were asked to bring a working (but not necessarily finished) model of their exhibit. The two-minute speech was to give the undergraduates the experience of pitching an idea quickly and concisely as well as the opportunity to explain their objectives and assessment. This was also the main opportunity for the teams to get feedback on their work before the actual event.

**Learning Styles**

The learning styles were presented to the class in their accompanying professional development lab. The topic of beam bending was used to illustrate the differences between styles of learning (active vs. reflective; intuitive vs. sensing; sequential vs. global; visual vs. verbal). The undergraduates were then separated into groups and asked to devise a “skit” that they would present to the class that would demonstrate how they would teach a simple concept using one learning (teaching) style. A fun example that was developed by an undergraduate team was how the “sequential learner” versus “global” learner would ask someone for a date. At the end of this lab class, the undergraduates were asked to determine their own learning style preferences using an online questionnaire developed by Felder. The distribution of learning styles for the class is presented in Figure 1. The general findings were that the students learning styles in this class were varied with students tending more lightly toward visual, sensing, sequential and active. There was also a reasonably good balance of learning preferences in this student population with students ranging between -3 to +3 on the Felder learning scale.
Exhibit day

The exhibit was presented in a large enclosed room within the science center. The students could set their exhibits up the day before or the morning of the “Body by Design” exhibit. One hundred 5th grade students from local elementary schools were invited to participate in this interactive project along with adult chaperones. There were eleven different interactive exhibits within “Body By Design” and these ranged in topic from preventing stagnant flow in heart valve designs to burst resistance in silicone vs. saline breast implants to fixed vs. mobile total knee bearing designs. As an example, one team was assigned “cemented versus uncemented hip replacements.” The undergraduates developed models with play-dough and wire meshes of varying hole size to demonstrate the effect of porosity on interpenetration. They also utilized changeable geometries and surface finishes between metal and wood to achieve different interface strengths. The children tested strengths in an inquiry-based format using varying weights. In addition the exhibit featured posters providing visual, verbal, and global perspectives as well as animations on their laptops for sequential learners. The exhibit offered active elements that were sequential and global; visual and verbal tools; intuitive and reflective learning through inquiries; and facts for sensing learners as well. The entire exhibit was documented with video camera that captured the individual projects, the interactions between students and children, and the diversity within the exhibit hall. Additionally, the students and participants were informally interviewed to assess the exhibit success. Figure 2 shows both interactive exhibits and student interactions within the “Body by Design” project. In addition to the interactive demonstrations, each team prepared posters that visually described their implants and many of the teams also provided video footage on their laptops. The 5th graders were free to come and go to any exhibit over a 1.5 hour period depending on their personal interests.
**Figure 2.** *Body by Design* activities with the undergraduates and the K-12 learners at the science museum.
Assessments

The undergraduates were asked their opinions of the outreach-teaching project in a questionnaire that addressed their assessments of course learning objectives (Figure 3). Collectively the undergraduates enrolled in this outreach teaching activity liked this project; however, it was found that female students generally enjoyed the outreach activity more than male students and found that this exercise served them in meeting course objectives. Some of the comments from the undergraduate groups were:

“I can’t believe how smart some of these kids are…”
“I was amazed by the level of interest and their attention span…”
“That was surprisingly fun…”
“After this project I think I am interested in pursuing a path in education…”
“Addressing the spectrum of learning styles facilitates broader interaction”
“Teaching is harder than it looks”

On final course evaluations, the majority of students (90%) stated that they enjoyed the experience of the outreach-teaching project and preferred this activity to the traditional final exam. At the completion of the semester the students provided a technical presentation to the class as well as a project report. In this presentation the students were assessed on their technical content and understanding of subject matter. Through this evaluation, it was determined that the course was successful in delivering the course learning objectives through an outreach activity rather than through a final examination as is traditional in the engineering courses. Peer evaluations revealed that the groups worked well together with little or no conflict. This outreach project provides a unique opportunity for undergraduate students to demonstrate their grasp of the subject matter while inspiring children to have a renewed interest in math, science and technology and the goal of becoming an engineer.

The children were not formally assessed in this project due to the limitations of human-subject studies; however, the young learners were informally interviewed while they were participating in the Body by Design exhibit. The children (and their adult mentors) thoroughly enjoyed the interactive exhibits and having the chance to meet “real engineers.” The majority of the students expressed that they had learned something new about engineering. One child said “I will consider engineering if it doesn’t work out for me in the NBA.”

The projects were not graded with a formal rubric but were evaluated with the following elements in mind: correct technical vocabulary (knowledge), organization of information and comparisons to relevant concepts (comprehension), identifying key elements of the problem and simplifying the problem (application), assumptions and tradeoffs in the design or solution (analysis), methodology and conclusions (synthesis), and assessment of limitations or consequences of their solutions (evaluation). Projects were assigned letter grades rather than numerical scores and prior to the project submission we defined to the class what we considered to be excellent work (A), good work (B), and acceptable work (C).
**Future directions and tips for consideration**

This style of final project has been highly successful in this multidisciplinary course. Extending this option within the curriculum and making such outreach activities available to our undergraduates has great potential for increasing the number of students who want to pursue engineering as a career path and it may be a useful tool in enhancing diversity within engineering. In doing so, it may be useful to develop more formal rubrics for project assessments and integration into the K-12 classroom. On the latter topic, we hope to implement a more formal relationship with the science classroom that enables us to work with the children several times over the course of the semester. Further integration into the elementary grade classrooms will help facilitate better teaching of engineering and science within the K-12 system. Additionally, we have plans to implement this type of program with alumni faculty at partnering institutions.

For faculty who wish to consider doing this type of outreach service project in one of their engineering courses, we offer that it is most useful to start well ahead and to work with an educational center or museum that can offer educational expertise for teaching at the K-12 level. Also, it is important to establish relationships with partnering schools so that the logistics and...
scheduling are well managed. Moreover, it is essential to have graduate student instructors or assistants who are passionate about engineering education and who ultimately enable successful implementation of the K-12 outreach project.

The near-term goal of this work is to extend the K-12 outreach activities to a lower division introductory engineering course in which students can be mentored through the teaching process. This activity is scheduled to be implemented in the coming year and will be facilitated through the children’s museum and several schools that target underrepresented students within the local K-12 school system.

The long term goals of this project are: (i) to disseminate science, engineering and technology information informally to the public, (ii) to create cognizant engineers skilled in teamwork, teaching, communication and outreach, and (iii) to create a national model that can be implemented in general engineering curricula and science museums to provide informal science education and accessible outreach teaching modules. In summation, K-12 outreach projects provide a unique opportunity for undergraduate students to demonstrate their grasp of the subject matter while inspiring children to develop their interest in math, science and technology with the goal of becoming an engineer.

References