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## **AC 2011-300: INTRODUCTION TO ENGINEERING DESIGN FOR FRESH-MAN: IMPLEMENTATION OF LEADERSHIP AND SERVICE LEARNING FOR BROADENING ENGINEERING INGENUITY**

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Research is focused on structure-property relationships in orthopedic tissues, biomaterials and medical polymers. Current projects include the assessment of fatigue fracture mechanisms and tribological performance of orthopedic biomaterials, as well as characterization of tissues and associated devices. Surface modifications using plasma chemistry are used to optimize polymers for medical applications. Attention is focused on wear, fatigue, fracture and multiaxial loading. Retrievals of orthopedic implants are characterized to model in vivo degradation and physiological loading. Medical implant analysis for structure-function-performance is performed to optimize device design. Biomechanical characterization of tissues is performed to assess clinical treatments and to develop constitutive relationships. Laboratory techniques for structural characterization include SEM, TEM, FEM, SAXS, USAXS, XPS, DSC, GPC, FTIR, AFM, confocal microscopy, wear testing, fatigue testing, fracture mechanics analysis, and nanoindentation. Research supported by NIH, NSF, ONR, DARPA, OREF and the medical device industry. Pedagogical experience includes curriculum development in mechanical engineering and bioengineering. Teaching experience includes undergraduate courses on Mechanical Behavior and Processing of Materials, Structural Aspects of Biomaterials, and Principles of Bioengineering; graduate courses on Fracture Mechanics, Mechanical Behavior of Materials, and Polymer Engineering.

# **Introduction to Engineering Design and Analysis for Freshman: Implementation of Leadership and Service Learning for Broadening Engineering Ingenuity**

## **Abstract**

*Engineering Design and Analysis* is a course offered at U.C. Berkeley that provides freshman with an introduction to the profession of engineering through a variety of small group design projects (modules). The primary objectives of the course are based on ABET criteria and are to: enhance critical thinking and design skills; introduce students to a broad view of engineering analysis and design; reinforce the importance of mathematics and science in engineering design and analysis; emphasize communication skills, both written and oral; develop teamwork skills; offer experience in hands-on, creative engineering projects; provide an introduction to different fields of engineering; and introduce students to the ethical context of engineering. This past year a service learning and leadership module was added to the traditional curriculum. Students worked in teams to teach the engineering design process to the k-12 sector in an informal science setting at the local children's museum. First year students were provided with the foundation for teamwork and leadership while engaging k-12 learners and the public in the engineering design process.

## **Course Description**

*Engineering Design and Analysis* is an introduction to the profession of engineering and its different disciplines through a variety of modular design and analysis projects. Hands-on creativity, teamwork, and effective communication are emphasized. Common lecture sessions address the essence of engineering design, the practice of engineering analysis, the societal context for engineering projects and the ethics of the engineering profession. Students develop design and analysis skills, and practice applying these skills to illustrative problems drawn from various engineering majors. This course provides first year students with a broad introduction to the profession of engineering and its different disciplines (bioengineering, civil engineering, industrial engineering, materials science and mechanical engineering). At the core of the course are projects and case studies, through which the main concepts of the course are developed. The objectives of the course are to enhance critical thinking and design skills; introduce students to a broad view of engineering analysis and design; reinforce the importance of mathematics and science in engineering design and analysis; emphasize communication skills, both written and oral; and develop teamwork skills. The course aims to deliver the criteria for graduating competent engineers as recommended by the Accreditation Board of Engineering and Technology. These criteria are summarized in Table 1.

**Table 1. ABET criteria for competent engineers**

Criteria	Description of competency
(a)	An ability to apply mathematics science and engineering principles
(b)	An ability to design and conduct experiments and interpret data
(c)	An ability to design a system, component, or process to meet desired needs
(d)	an ability to function on multidisciplinary teams
(e)	an ability to identify, formulate, and solve engineering problems
(f)	an understanding of professional and ethical responsibility
(g)	an ability to communicate effectively
(h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i)	a recognition of the need for, and an ability to engage in life-long learning
(j)	a knowledge of contemporary issues
(k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

## Course structure

The first three weeks of the semester comprise general engineering lectures that provide an overview of the various engineering disciplines including bioengineering, civil engineering, industrial engineering an operations, materials science, and mechanical engineering. In this timeframe, students are also given lectures on the topics of engineering failure analysis, design methodology, and ethics. Following the general lectures in the first three weeks are two sets of 5-week modules. One faculty member administers each module of approximately 60 students for three hours of lecture and three hours of lab each week. Each lab comprises approximately 20 students. The small-group lab sections allow student teams to address the module topic in depth. Students are assigned homework during the modules and at its completion they write a technical report and provide an oral presentation. Historically, the modules have focused within the traditional disciplines of engineering. A new module entitled ***Leadership and Service Learning for Broadening Engineering Ingenuity*** was implemented using k-12 service learning for professional development of our young engineers.<sup>1</sup>

### ***Leadership module***

This module provides the framework for development of the core competencies necessary for leadership in the context of broadening engineering excellence and design ingenuity. The module presents the processes in engineering design, mechanisms for developing personal and team leadership styles; addresses differences in learning and personality styles; provides pathways process for implementing mission statements and plans of action; and offers opportunities for strategic thinking, problem solving and brainstorming; and utilizes teamwork

in diverse settings for societal and k-12 service learning including outreach teaching activities. The technical foundation of this module is centered upon the process of engineering design and implementation of ingenuity projects in collaboration with our local children's museum, the Lawrence Hall of Science (LHS).

#### *Lecture description*

A module on the topic of leadership and service provides the framework for professional development. The lecture aspect (3hrs/week) of the module presents mechanisms for developing personal and team leadership styles; addresses differences in learning and personality styles; provides pathways for creating mission statements and plans of action; and offers opportunities for strategic thinking, problem solving and brainstorming, and teamwork. Table 2 provides a summary of the lecture topics provided within the leadership framework.

**Table 2. Leadership lectures**

#### **Development of Self:**

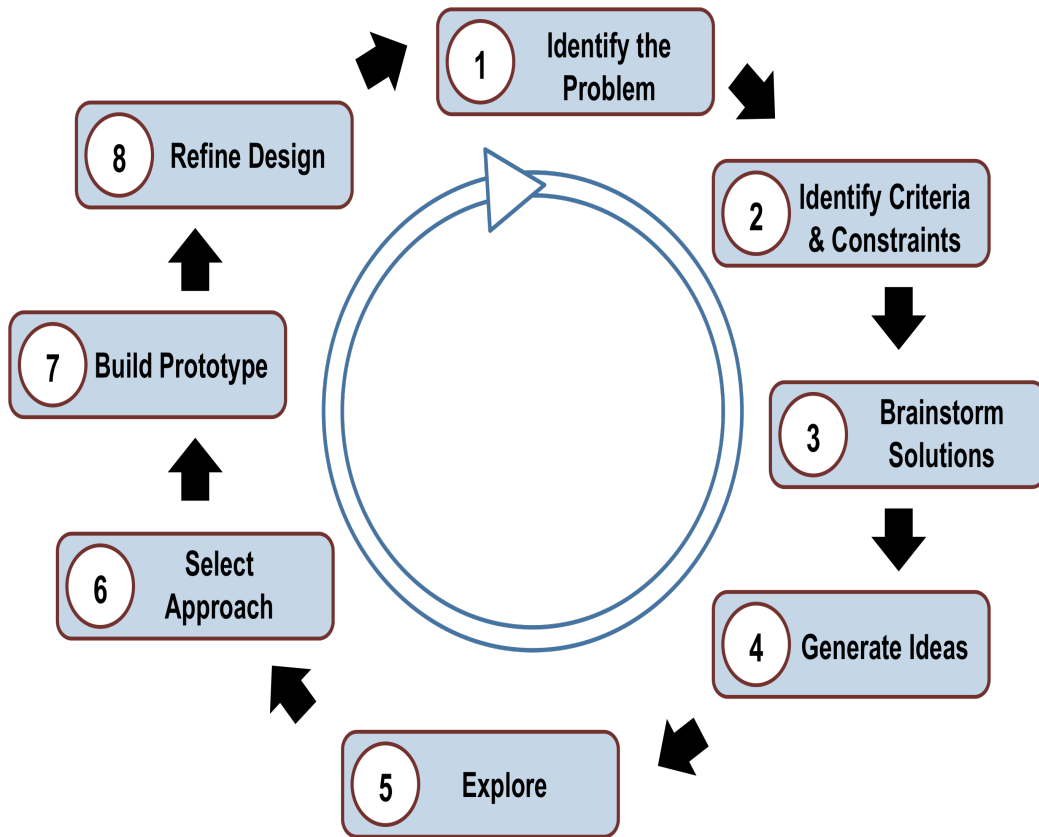
Assessment of personal strengths and weaknesses. Building congruency, trust and ethical standards (development of a personal mission statement). Life balance and time management as a practice. Awareness of body language and voice. Strategic thinking and problem solving. Creativity, brainstorming and innovation. 3Cs of leadership (Competence, compassion, and chronos). Personal leadership styles.

#### **Diversity and Teamwork:**

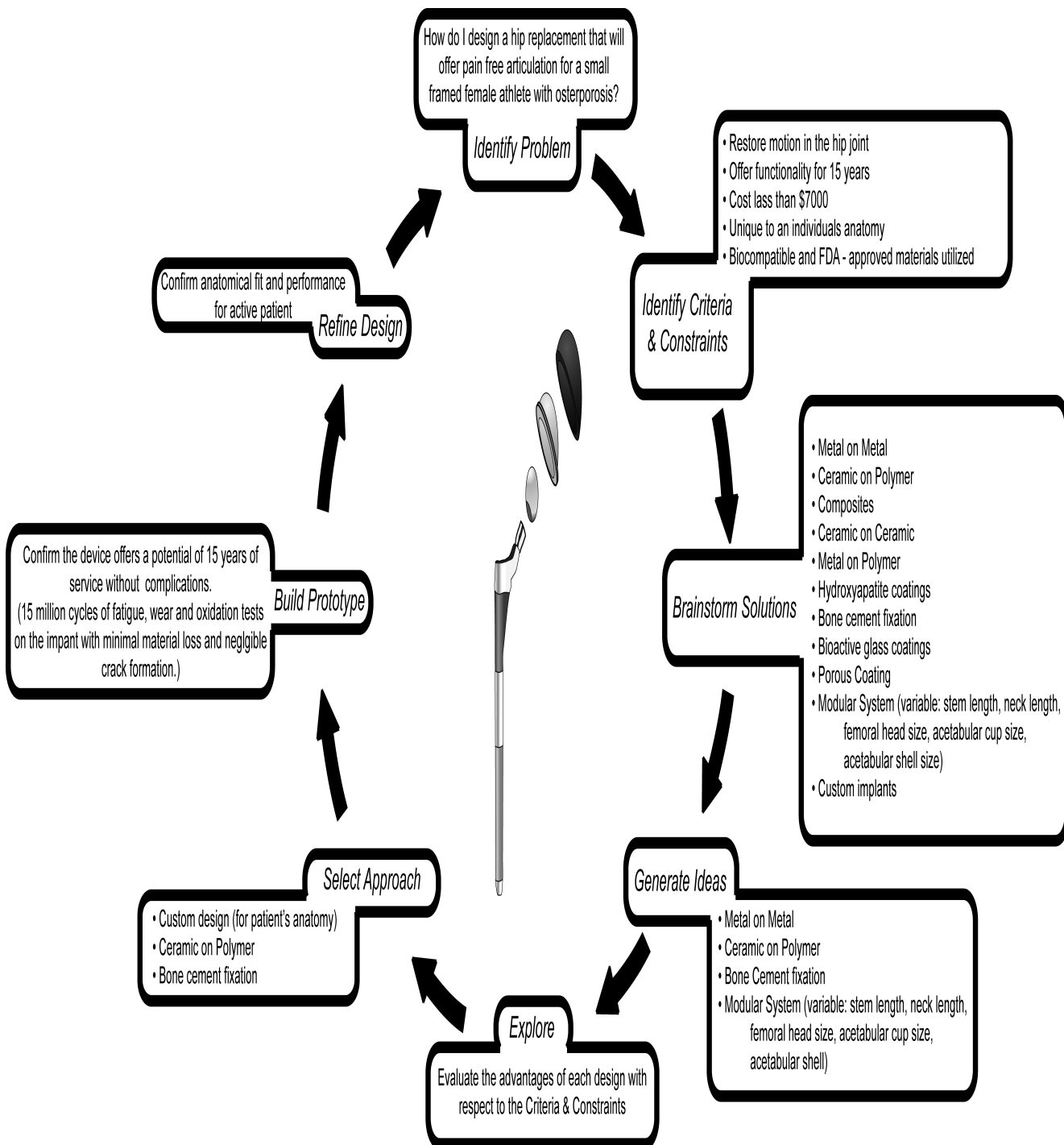
Embracing differences in personality (Myer-Briggs) and learning styles (Global vs. Sequential; Intuitive vs. Sensing, Active vs. Reflective; Verbal vs. Visual). Decision trees and methods for mentoring. Group communication and conflict management tools. Development of a plan of action (formulation, negotiation, fulfillment, and review). Project lifecycles and rhythm of action for teamwork.

**K-12 outreach:** Levels of learning (Bloom's taxonomy). Teaching methodologies in the K-12 domain and the public sector (societal service).

The heart of the leadership module is centered upon the 8-step design process (Figure 1). The concept is presented in lecture as a standard format for the engineering design process. One week of lecture is devoted to the use of the design loop and its iterative elements. A total hip replacement design is used as a case example of how teamwork and engineering decisions are utilized in a modern medical device (Figure 2). Within this active exercise, the students are given opportunities for brainstorming, conflict resolution and ethical decisions within the framework of this case study. Additionally, the students are provided with a working template of the design loop that translates to their service learning project that aims to teach the design process to the k-12 sector (as discussed below).



**Figure 1. 8-step design loop**



**Figure 2. The design process applied to a total hip replacement design and used as an active exercise in the first year design class.**

Another portion of the leadership module that directly translates into service learning is the utilization of learning styles as defined by Felder and Silverman.<sup>2,3</sup> The learning styles (Table 3) are presented in lecture using active exercises to teach the concepts associated with each learning modality (in addition to using a case example of beam bending for all learning styles). For example, simple exercises of making a peanut butter and jelly sandwich, playing cards, and box building are used to teach the different learning modalities. Students work on these exercises in a group setting and present skits to the class. As a homework assignment the students are also asked to complete an online assessment of their individual learning style.<sup>2</sup> The learning styles for each student are added to each team member's name card and this information is used as an opportunity for diversification and team building. An understanding of the learning styles serves as a template for the service learning deliverable as each team is asked to develop a teaching project that both encompasses the engineering design process and that addresses all of the learning styles (the project description follows below).

**Table 3. Learning styles and their characteristic traits.** <sup>2,3</sup>

<b>Learning continuum</b>	<b><i>Learning styles</i></b>	<b><i>Characteristics</i></b>
<b>Perception</b>	<b><i>Sensing</i></b>	<i>focus on external inputs (see, hear, touch) and tend to be practical and prefer facts, data, and experimentation</i>
	<b><i>Intuitive</i></b>	<i>focus on internal inputs (thoughts, memories, images) and tend to be imaginative and prefer principles, theories, and models</i>
<b>Input</b>	<b><i>Visual</i></b>	<i>tend to remember what they see (pictures, charts, diagrams)</i>
	<b><i>Verbal</i></b>	<i>tend to remember what they hear and read</i>
<b>Processing</b>	<b><i>Active</i></b>	<i>learn best when doing active experimentation or discussion and prefer group work</i>
	<b><i>Reflective</i></b>	<i>prefer to observe experiments, think about information introspectively, and favor individual assignments</i>
<b>Understanding</b>	<b><i>Sequential</i></b>	<i>like to have information presented in a linear fashion with each new idea building from that previously learned</i>
	<b><i>Global</i></b>	<i>need to understand how all of the information relates to each other before they can understand the details</i>

### *Lab description*

The hands-on aspect of the module (3hrs/week) involves service teaching in the k-12 sector and is centered upon the implementation of team teaching projects entitled “*Ingenuity in Action.*” These projects are developed and implemented by the freshman enrolled in the course in collaboration with the local children’s science museum, Lawrence Hall of Science (LHS). The *Ingenuity in Action* projects developed by the freshman groups utilize the *8-step design process* and allow for the creative experience of k-12 students who participate in the exhibit. In the first week of the leadership module, the first-year engineering students are self-assembled into teams of four and they meet in a lab setting for 3 hours each week for a total of 5 weeks. In addition, each team member is required to provide 8 hours of service learning at LHS as part of their project deliverable. In this time (8 hours) the undergraduates interact directly with the children and teach the k-12 visitors about the engineering design process. This format provides an opportunity for teamwork that will serve students well in the engineering discipline.<sup>4</sup>

The service learning project implemented at the science museum requires the students to design and implement a facilitation strategy for making the engineering design process explicit to LHS visitors. The first year students have two primary options for activities:

**1. Adapt an existing activity in the *Ingenuity in Action* exhibit.** The *Ingenuity in Action* exhibit is housed on the main museum floor and features three activity stations. The students choosing this option are required to revise the facilitation process and add the *encapsulation of the engineering design process (Figure 1)* to the activity. Within this exhibit there are three activity stations:

- (i) ***Fly High***: Create your own flying machine and test it in a wind tube. This is a highly open-ended design challenge.
- (ii) ***Design and Drive***: Combine wheels and treads to optimize your vehicle for climbing on rough surfaces. This project is more constrained due to requirements of gear ratios and terrain, etc.
- (iii) ***Span the Gap***: Experiment with the basic building of bridges (inspired by the Bay Bridge) to create your own. This design challenge is constrained by a number of factors including safety and efficacy.

**2. Develop *new challenge* for the *Ingenuity Lab*.**

The *Ingenuity Lab* contains building blocks, motors, gears, programmable microchips, basic circuitry materials, and other interesting materials. Develop a design challenge for visitors making use of the materials available in that lab space and illustrating the engineering Design process. Facilitating the challenge activity with LHS visitors in the *Ingenuity Lab* completes this project.

Regardless of the option chosen, the service learning activity needs to allow for visitors to develop their own creative solution to the challenge. Additionally, the activity must encompass all the learning modalities as defined by Felder (Table 2). Also, the activity must provide an exercise that teaches the engineering design process and yet remain fun for k-12 visitors.



## Student projects

Over the course of the semester, the 5-week leadership module was offered two times. Each module comprised 80 engineering students (160 students total). The groups developed teaching activities that were near-equally dispersed amongst the project options described above. A representative teaching activity from each of the projects options is given below:

### *Fly High*

For the wind tube design challenge, one of the first-year engineering student teams developed a storyboard narrative to draw visitors into the exhibit with the challenge of rescuing stranded soldiers. The constraints are imposed with the limited choices of materials (design kit) made available to the k-12 visitors. This group used 4 stations to capture the design process: (1) problem statement and welcome sign, (2) brainstorming, (3) materials selection and (4) prototyping.

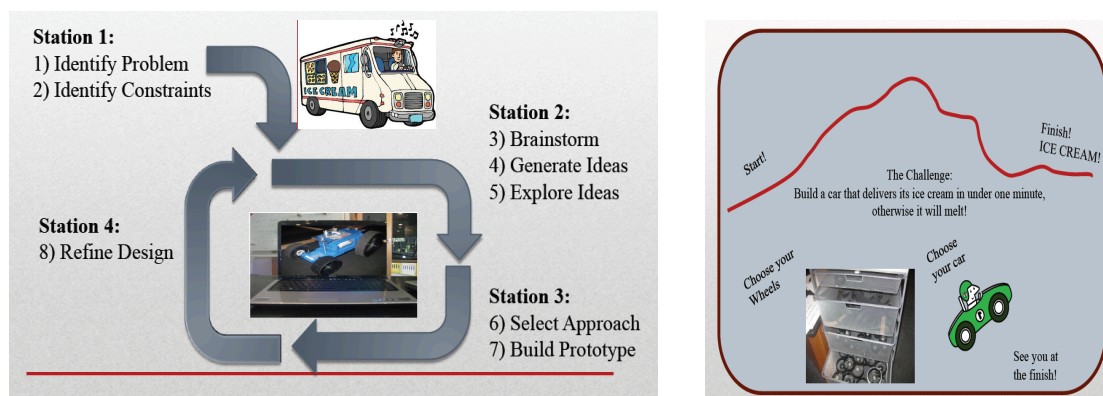


**Figure 3. Storyboard narrative depicting the design challenge of rescuing soldiers using the Fly High exhibit.**

### *Design and Drive*

One of the engineering teams developed a playful concept of designing an ice cream truck that could navigate the terrain of their village and deliver the ice cream to all the children in less

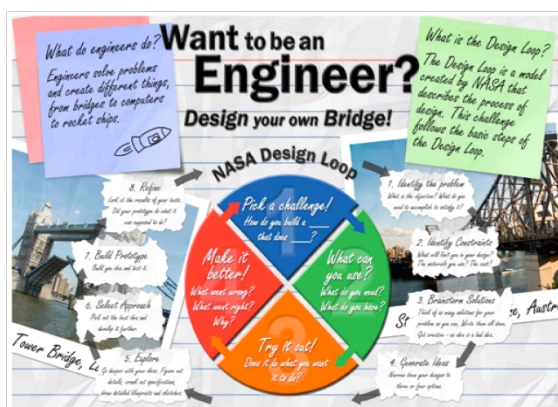
than 1 minute. This group utilized the vehicles supplied by LHS and added age limitations for the push-car prototypes (5 and under) and the geared cars (6 and above). The students offered design constraints of different gear ratios and wheel sizes to adjust for speed and tractability for the challenge course. To teach the design process, the team developed a video that divided the 8-step design process into four stations (Figure 4). The students themselves were the actors and they narrated the audience through the design process in their filmed documentary. The students addressed the different learning styles using different demonstrations and the exhibit was set up with four stations that encapsulated the design process. To provide a competitive spirit the students develop a leader board that captured the names and drive times of the visitors.



**Figure 4. Example of the design challenge used for the Design and Drive exhibit.**

### *Span the Gap*

One of the engineering teams developed professional quality graphics to bring the visitor into their exhibit challenge of bridge building. To address age differences the team developed a series of challenges centered upon bridge span and weight bearing capabilities. The first year students utilize well-known bridge designs and translate the 8-step design loop into an elementary loop with four components that they use to navigate the visitors through their bridge design exhibit (Figure 5).

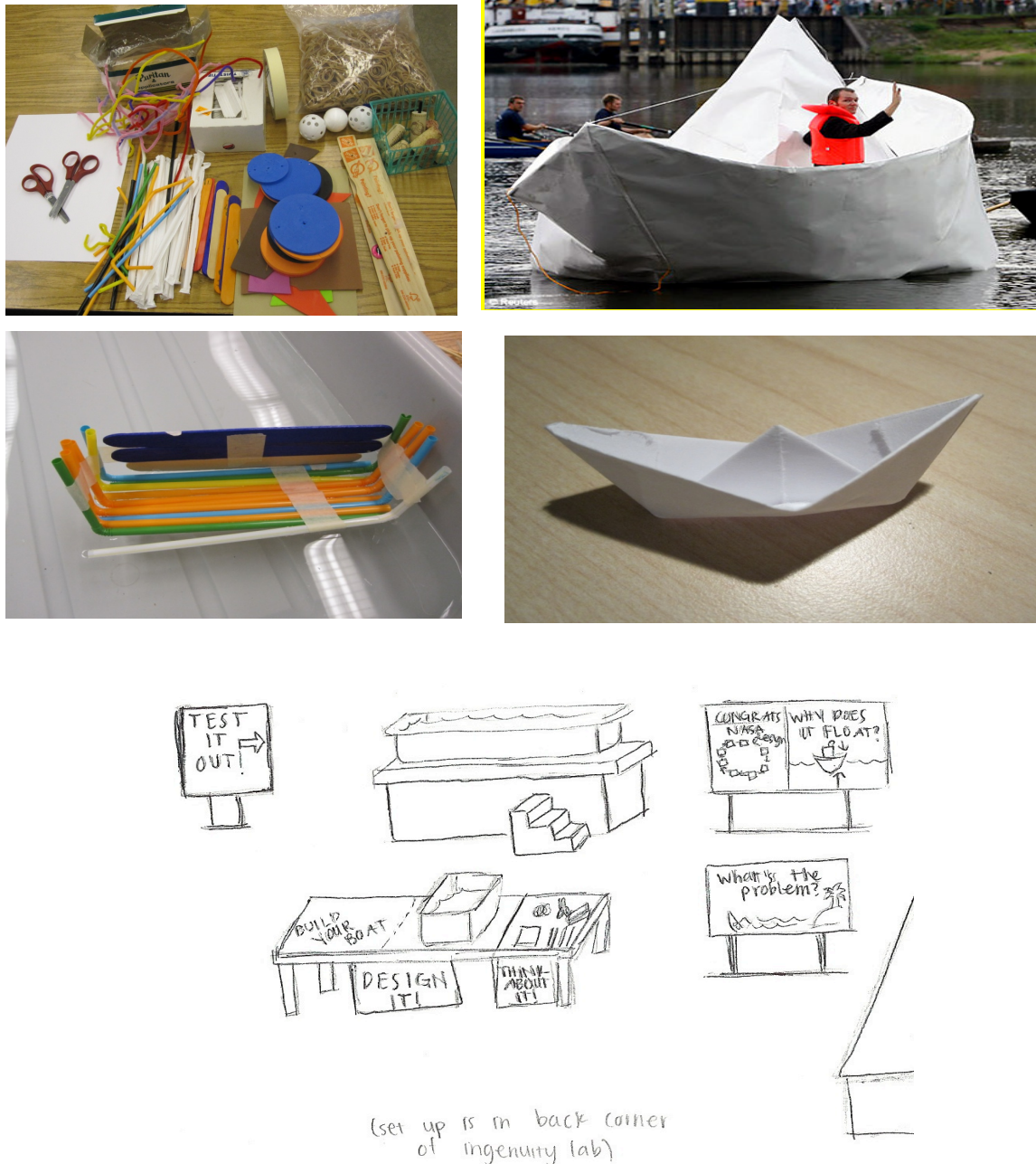


**Figure 5. Illustration of a design process used in the bridge building exhibit.**

## ***Ingenuity Lab***

### ***Sink or Sail***

One group developed a project in the ingenuity lab and utilized the concept of “sink or sail” as a creative challenge for the k-12 visitors. They used four stations to capture the design process: (1) problem identification and constraints (materials), (2) brainstorming, (3) explore, select and build, and (4) refine design.



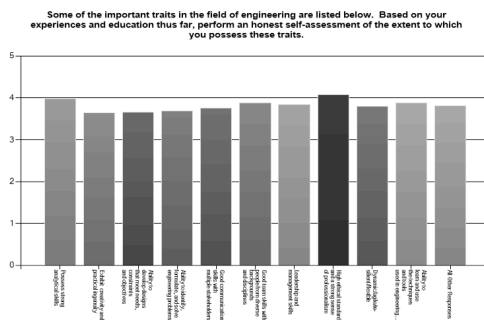
**Figure 6. Four stations utilized in the “sink or sail” challenge.**

## Educational outcomes

Through active participation in this course, students recognize the role of mathematics and science in engineering; understand the design of systems, components, and processes to meet desired needs within realistic constraints; gain experience in working in multi-disciplinary teams; develop early abilities in identifying, formulating, and solving engineering problems; appreciate the importance of professional and ethical responsibility in engineering; obtain experience in effective communication; begin to understand the impact of engineering solutions in a global, economic, environmental, and societal context; and begin to use the techniques, skills, and engineering tools necessary for contemporary and future engineering practice.

## Assessments

As part of the leadership module, all individuals were asked to take a survey providing their basic background information (intended major, ethnicity, personality style, and learning styles) and their confidence in basic engineering skills as defined by ABET (Table 1). The basic engineering questions, as shown in Figure 7, were provided at the start of the semester and then were re-evaluated at the end of the module using a retrospective comparison. The majority of the students demonstrated learning styles that were active, sequential, visual, and intuitive. Students reported an improved self-assessment of their engineering skills at the completion of the module.



	Low (1)	Medium Low (2)	Neutral (3)	Medium High (4)	High (5)	Rating Average
Possess strong analytical skills	0.0% (0)	1.4% (1)	20.3% (15)	58.1% (43)	20.3% (15)	3.97
Exhibit creativity and practical ingenuity	1.4% (1)	10.8% (8)	25.7% (19)	47.3% (35)	14.9% (11)	3.64
Ability to develop designs that meet needs, constraints and objectives	0.0% (0)	6.8% (5)	39.2% (29)	35.1% (26)	18.9% (14)	3.66
Ability to identify, formulate, and solve engineering problems	0.0% (0)	8.1% (6)	31.1% (23)	45.9% (34)	14.9% (11)	3.68
Good communication skills with multiple stakeholders	0.0% (0)	13.5% (10)	23.0% (17)	37.8% (28)	25.7% (19)	3.76
Good team skills with people from diverse backgrounds and disciplines	1.4% (1)	10.8% (8)	14.9% (11)	44.6% (33)	28.4% (21)	3.88
Leadership and management skills	1.4% (1)	5.4% (4)	29.7% (22)	35.1% (26)	28.4% (21)	3.84
High ethical standards and a strong sense of professionalism	1.4% (1)	6.8% (5)	16.2% (12)	33.8% (25)	41.9% (31)	4.08
Dynamic/agile/resilient/flexible	0.0% (0)	6.8% (5)	25.7% (19)	48.6% (36)	18.9% (14)	3.80
Ability to learn and use the techniques and tools used in engineering practice	0.0% (0)	5.4% (4)	17.6% (13)	60.8% (45)	16.2% (12)	3.88
Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis	0.0% (0)	6.8% (5)	24.3% (18)	50.0% (37)	18.9% (14)	3.81

**Figure 7. Self-assessment of engineering skills provided at beginning and end of module.**

## Conclusions and Recommendations

Overall the offering of a leadership module was a success. Students enhanced their teamwork skill sets and met the ABET criteria for graduating engineers while providing a service to the k-12 sector. Each engineering team interfaced with k-12 students for a minimum of 8 hours of service learning over a 5-week period. The course module itself was popular and ranked 2nd for teaching effectiveness in the Department of Mechanical Engineering. An unexpected outcome of the course was that several (20) students went on to work at the children's museum part time or joined our engineering society committed to outreach education in the local elementary schools, middle schools, and high schools. This type of project is ideally initiated in the first year of the engineering program and then balanced in other courses throughout their undergraduate curriculum. The greatest "challenge" in offering a "leadership" module within the framework of engineering is that there were a few engineering students (5 students out of 150 students enrolled in the module) who truly did not enjoy the activity of teaching children and these students felt that this activity was completely inappropriate in an engineering course. This was dealt with recently by offering this module as a specialty topic entitled, "Teaching as Leadership" and the educational goals were made clear at the start of the module selection process. This ensured that students who were not interested in such an activity could choose a "traditional" engineering module instead.

## References

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