Incorporating an Entrepreneurial Mindset in a Freshman Mechanical Engineering Course

Chiradeep Sen and Pierre Larochelle
Florida Institute of Technology, csen@fit.edu, pierrel@fit.edu

Abstract **- This paper presents a case of incorporating Project-Based Learning (PBL) and Entrepreneurially-Minded Learning (EML) to foster an entrepreneurial mindset in a freshman-level, introductory course in mechanical engineering within an ABET accredited program. The course is designed to teach the basic tools and skills of engineering such as graphics communication, solid modeling, and programming, with a large term project where students design and build an engineering system. The teaching method included two novel elements that were introduced in Fall 2015: (1) the tools and methods for systems design were taught using a Project-Based Learning module, and (2) the term project was changed from a design and build project to an entrepreneurial engineering project. The resulting designs were highly varied within the class and of higher quality than the more traditional approach, where the instructor assigned the same problem to each team.**

Index Terms - Entrepreneurial Mindset, Entrepreneurially-Minded Learning, Project-Based Learning

BACKGROUND AND SETTING

This paper presents a case of implementing Project-Based Learning (PBL) and Entrepreneurially-Minded Learning (EML) methods into a freshman-level, introductory Mechanical Engineering course at Florida Institute of Technology (Florida Tech). This section provides the environment and context within which first year pedagogy innovations were deployed

I. The University

Florida Institute of Technology is a private university located in Melbourne, Florida. It is located in Brevard County—the so-called Florida Space Coast—within 40 miles from NASA's Kennedy Space Center, and is surrounded by several of the world's leading corporations in aerospace and aeronautical engineering, and federal defense contractors. The school was established in 1958 specifically to provide graduate-level education to the engineers of Cape Canaveral (now Kennedy Space Center) [1] and has evolved into a research-intensive university with strong undergraduate focus. It is ranked among the top 200 universities in the world according to Times Higher Education World University Rankings 2014-2015 [2]. The school has approximately 9000 students, of which approximately 4600 are in the main campus in Melbourne [2]. College of Engineering is the largest of the five colleges in the university and Mechanical Engineering has the largest enrollment among the nine ABET accredited undergraduate engineering programs within the College.

II. The Course and its Logistics

The course in which PBL and EML were implemented in Fall 2015 is MAE 1024: Introduction to Mechanical Engineering. It is the largest enrolled course in the College of Engineering, with 120-160 freshmen registering each fall, mainly from the mechanical engineering major. The students are divided into two lecture sections and eight lab sections. Both lecture sections are taught by the same professor, while the lab sections are taught by a team of six to eight teaching assistants (TAs) and supported by one grader. Each student receives 100 minutes of lecture instruction and 150 minutes of lab instruction per week.

The catalog description of the course is: Provides an overview of the engineering profession and the mechanical engineering discipline. Introduces students to engineering problem-solving methodologies and design theory and methodology. A competitive design project motivates the study of engineering graphics, computer-aided design, manufacturing techniques and software tools. The course is designed to teach the basic skills of engineering, such as sketching, engineering drawing, solids modeling, engineering computation, programming, and an overview of the curriculum, profession, achievements, challenges, future directions, and job opportunities in mechanical engineering. A large portion of the grade comes from a semester-long project in which student teams design and build an engineering system. The number of teams varies between 25 and 30 depending on enrollment.

PBL AND THE "ENTREPRENEURIAL MINDSET"

I. Project-Based Learning (PBL)

Project-Based Learning (PBL) is a teaching method where students learn by working for an extended period of time on a real-world and authentic problem or project that is carefully selected or designed to require the knowledge and skills that the teacher intends to deliver [3]. This pedagogy is designed to engage students better than traditional lecture-based methods. By the very nature of the assignment, students are forced to ask questions about the problem, form an implicit problem statement, explore solution strategies, compare

alternatives, and work in teams [4-7]. PBL assignments have these common features [5]:

- They start with a driving question, problem, or project.
- Students explore the problem through authentic situated enquiry. The problem must be a real-life or realistic one (authentic).
- Students and teachers participate to analyze and explore the problem and solution possibilities collaboratively.
- Student scaffold on externally available information to learn more about the problem.
- Students create a sharable tangible artifact as a result of the activity, which can be graded.

In the course discussed here, PBL was used to teach the tools and methods for producing realistic solutions to previously unseen, novel problems, and to demonstrate to the freshmen that design is, and should be, a systematic and intentional activity, rather than one relying on chances and lucky breaks of creativity.

II. The "Entrepreneurial Mindset" and EML

The term *entrepreneur* is often understood in the common parlance to describe "a person who starts a business and is willing to risk loss in order to make money" [8]. Notably, the *entrepreneurial mindset* mentioned in this paper does not refer to the mindset of starting new businesses. Instead, it refers to three desired qualities in an engineering student, given by three C's: (1) **C**uriosity, (2) **C**onnections, and (3) **C**reating value [9].

It should be noted that this approach of instilling the entrepreneurial mindset in engineering courses is part of a larger initiative throughout the College of Engineering, funded by an institutional grant from a not-for-profit organization called the Kern Entrepreneurial Engineering Network (KEEN) [10], a nationwide network of engineering programs with a shared mission of fostering such mindset, and its parent organization: the Kern Family Foundation [11]. Florida Tech is one of the 24 member institutes of this network. KEEN posits that the entrepreneurial mindset, coupled with the technical skillset developed through the curriculum, is necessary to produce graduates who will create "personal, economic, and societal value through a lifetime of meaningful work" [9]. It should be noted that such claims have not been defended by academic research, but are deemed sensible by engineering faculty throughout the KEEN network and by the authors. The three C's are explained in the context of a design project below. The term project assignment was designed to stimulate student learning of these three C's.

- **Curiosity** is the designer's tendency to identify and learn about the stakeholders of their work, and to learn about the world and society that will constrain, impact, and be impacted by his or her engineering works. It also is the quality to challenge currently accepted solutions and posit contrarian viewpoints [12]. For example, curiosity forces the designer to challenge the requirements stated by the customer and seek insight into the true pain points of the customer that generated those requirements. Especially in outreach projects, the curiosity to understand the living conditions, economic condition, and life's priorities of the target communities can be crucial for developing a successful product.
- **Connections** is the ability to integrate information from many sources to gain insight [12] and to relate and join disjointed ideas into consistent themes. For example, in an outreach project, integrating the information about the target demographic obtained from various sources, such as reading, watching videos, or interviewing members of the community can provide an overall picture of the users that can be crucial in assessing if a design idea would be successful or not.
- **Creating Value** is the attitude toward maximizing the benefit to the customer and other stakeholders by doing the engineering work. Value can be defined as the utility of the product or service per unit cost [13].

SUMMARY OF THE CHANGES IMPLEMENTED IN CLASS

I. The "Before" Picture (Fall 2014)

Before implementing PBL, the term project assignment used to have the following characteristics:

- The students used to be tasked with designing and building a product, rather than solving a problem.
- The assignment came from the instructor, without participation from the students.
- All teams in the class were assigned the same product to build.

Examples of products include pinball machines, robotic games, etc. A project assignment could begin as: "Design and build a pinball machine, which will…". Students had to accept the assigned product regardless of their interests. Since the assignment was not presented as a problem faced by a segment of customers that needed to be solved, it did not necessarily force the students to see engineering as a means to serve humanity or customers by creating value for them.

The design outcomes from the class under this setting varied mainly in external appearance and aesthetics, rather than in working principles or application of technology. For example, the pinball machines of Fall 2014 had various external themes (e.g., housed in a boat frame, video games color schemes), in placing the obstacles for the ball, the scoring scheme of the game, in the display of scores, and in the light and sound produced for aesthetics. The mechanical design of all but one pinball machine was inspired directly by the pinball machines commonly seen in gaming zones. The exception was one team's machine, where the frame was mounted on a custom-built gimbal system, giving a fundamentally different user experience in the response of the ball to user actions. Many machines did not function properly. In years prior to 2014, the assigned products were technically more challenging than pinball machines, such as robotic soccer games, unfortunately there is insufficient data available to report on those projects.

II. The "After" Picture (Fall 2015)

In Fall 2015, the teaching approach differed from the pre-2015 model in two ways:

(1) A **PBL module** was introduced to teach the tools and methods of system design in class, and

(2) The term project was changed from a design project to an **entrepreneurial engineering project** by incorporating EML techniques. This project fostered curiosity, connections, and creating value, collectively called the entrepreneurial mindset. These two elements are discussed below in detail.

PBL MODULE FOR CONCEPTUAL DESIGN SYNTHESIS

The PBL module was developed to teach students the tools and methods of solution synthesis and to demonstrate the importance of following a systematic and tractable process and documenting the steps of progressive decision-making. Salient points of this module are discussed here.

I. Hook Statement and Progressive Disclosure

The tools and methods of system design and analysis were taught during class time, using a Project-Based Learning module. The following statement was used as the hook statement of the PBL project, and was solved in class over 10 class periods. The root cause of the problem was not disclosed on the first day, allowing students the opportunity to exercise their curiosity and consider conflicting and contrarian views of the possible causes. This ambiguity also provided an in-situ experience of doing engineering design under uncertainty, conflicting information, and changing scope. In the middle of the second class period, the root cause was progressively disclosed, in order to help focus the remaining class discussions.

- **Hook Statement**: "The fast food restaurant industry constantly monitors the quality of service offered in their restaurants. A recent, multi-year, national-level study conducted by a fast food market leader identified that the speed and accuracy of order delivery on both drive-through and over-the-counter services reduces significantly during summer. The company has floated a design challenge especially directed to engineering student teams, asking for innovative solutions to this problem to be submitted as formal reports. A monetary award of $5,000 has been announced for the winning team, while an "all you can eat-in" coupon valid for one month has been announced for each team member of the first 100 entries. Develop a concept for the automatic burger-maker and submit a design report."
- **Progressive Disclosure**: "Further internal analysis by the company indicates that this reduction may have a causal relation with the hiring of short-term employees, often untrained and inexperienced, to staff these restaurants during the summer. While summer employment is financially beneficial to the company and its employees, the company needs to ensure reliable order processing to protect its image and market share. The company is looking for innovative solutions to automate the burger-making process that will perform reliably despite unskilled labor."

II. Topics and Duration

Over a period of ten class periods (five weeks) the following elements of systematic conceptual design were taught. The problem statement above was used as a mini project, at each step of which, the design tools were used to progressively and systematically derive the solution state from the problem state. Each step was done collaboratively between the teacher and the students: by first showing them what each tool does and how to use them, then doing the first few steps of the tool for the hook statement, and finally asking the students to finish using the tool on the hook statement in class, under the guidance of the professor.

- Day 1-3: Requirements Checklist [14]
- Day 4: Ideation: Brainstorming [15]
- Day 5: Ideation: C-Sketch [16]
- Day 6-9: Function Modeling [15, 17, 18]
- Day 10: Morphological Analysis [14]
- Day 10: Decision Matrix [14]

III. Distribution of Work Load

The total work content of the PBL module was distributed between class, lab, and out-of-class assignment, as follows:

- **In Class**: All five modules
- **In-Lab**: TAs review class lessons, answer questions, clarify doubts, and give more practice to the students
- **Out-of-Class**:
  - **Function modeling homework**: build the function model of the vacuum cleaner shown and described at home.howstuffworks.com/vacuum-cleaner.htm.
  - **Reflective writing assignment**: Write a reflective essay about your learning experience. Do you think using the design tools helps or curbs your creativity?

IV. Evaluation Guidelines

Students produced "tangible sharable outcomes" at each step [5]. The following guidelines were used to prepare rubrics for assessing student work under each heading.

- **Requirements**
  - Is the subject of the requirement clearly identified?
  - Is the requirement SSSMART, as taught in class (Solution-neutral, Specific, Separable, Measurable, Achievable, Rational, Testable)
- **Ideation: Brainstorming**
  - Was the session captured in video?
  - Was there an assigned scribe?
  - Was there a timekeeper?
  - Was the written report shared?
- **Ideation: Collaborative Sketch (C-Sketch)**
  - Was there a team of 3-5 designers?
  - Is there evidence of progressive improvement or edits to the design, such as difference in pen color between successive designers?
- **Function Modeling**

- Are both the tree view and graph view presented?
- In the graph view, do the blocks represent verbs (actions) and arrows represent objects (flows)?
- In the graph view, are material, energy, and signal flows identified by line font?
- In the tree view, are the sub-functions correct?
- Is the model physically consistent?
- Is the model logically consistent?
- Are the function blocks of the graph view derived from the leaf nodes of the tree view?

- **Morphological Chart**
  - Is there at least two solution principles identified for each function?
  - Do the principles vary sufficiently, e.g., by the use of energy and material forms, or the use of physics phenomena?
  - Are the solution principles connected to form working structures?
- **Decision Matrix**
  - Are decision criteria identified? Are they defended by rationale?
  - Are weights identified for each criterion?
  - Are the best, the worst, and a medium idea noted?
  - Is the justification of the numeric analysis and its comparison against the perception of the designer presented at the end (2-3 sentences)?

THE ENTREPRENEURIAL ENGINEERING PROJECT (EML)

After the students practiced the design tools and methods through the PBL module, they applied them to the term project. As stated earlier, the term project was designed as an entrepreneurial engineering project, which was done by incorporating four elements of EML, as explained below.

- **Present a Problem Scenario**: Instead of a *product* to be designed, a *socio-technical problem scenario of common interest* was presented. In Fall 2015, the topic was energy: one that has technical as well as social, economic, and political significance. The scenario was presented as a small essay written in the context of the increased global energy demand, depleting fossil fuel reserves, increased thrust on low-emission and alternate sources, and increased public awareness of global climate change. The scenario did not end with a task or a problem statement; it was only meant to inspire the students and invoke awareness of a global problem to which engineers could have a tremendous impact.
- **Empower Students**: A problem statement was formed, but it was intentionally left open-ended, to permit individual and team creativity and to foster the 3 C's. The literal problem statement was:
  - "Design, build, and demonstrate a novel and non-conventional means to harvest/save/produce energy with a low environmental impact. <u>You have to come up with your own product idea</u>. Applications suitable for industrial, commercial, or consumer usage are equally encouraged. Be mindful that you must design, build, and present an appropriately scaled functioning prototype in a semester's time."

With this open-ended statement, student teams face a multi-objective decision problem, akin to the ones faced by an entrepreneur in the market. Within a short time, they must identify a pain faced by a market that could have a technical solution, understand value propositions and requirements, innovate multiple solution ideas, evaluate and compare them, assess the feasibility of realizing the idea within the given time and the skills and resources available in the team, and demonstrate their working idea to a judge. This vast open-endedness initially discouraged some teams, nevertheless teams usually matured out of that initial setback within the first 3-5 weeks of the term. With this problem statement, the ownership of finding a problem to solve is transferred to the student, which (1) empowers the students, (2) ensures better dedication to the project, and (3) gives this project its entrepreneurial nature.

- **Ask for a Proposal**: The first deliverable required from the team was not a design outcome, but a *proposal*, where students had to demonstrate their understanding of the social need, technical challenges, the risks, and the likelihood of success based on the resources and skills in the team and the challenges of the project. The teams must demonstrate that they visited multiple ideas before choosing one. They also must demonstrate that their work, if fully implemented, would create value for the customer.
- **Provide Collaborative Guidance**: Through the life of the project, the student teams were given technical and administrative guidance and advice through a consorted effort between the professor and the TAs. No direct help, e.g. ideas or technical details, was provided. However, teams were provided assistance with evaluating various ideas.

RESULTS: STUDENT WORK OUTCOMES

I. Results from the PBL Module

Representative samples of student work are presented here for illustration. FIGURE 1 shows function models of a hair dryer, performed by a student in class. While the text in the image may not be legible, it is clear that the student created two views of the function model: (1) the tree view in the bottom and (2) the graph view in the top. This task was assigned in class, after function modeling was learned and practiced using the hook statement (fast food problem) on day 7. FIGURE 2 shows the function model of a vacuum cleaner constructed by a student in homework assigned at the end of day 7. The evidence that the student learned the art and purpose of function modeling from practicing it in class is evident. It is also evident that the student was able to decompose the design system by progressively dividing larger functions into sub-functions. Exploring various ways to decompose a given system in this manner forces the student to learn about alternate solutions, their technologies, and comparative advantages, which fosters the three C's.

Notably, the use of formal vocabularies and languages [19, 20] were not yet taught, so the use of the natural English language is apparent in the models.

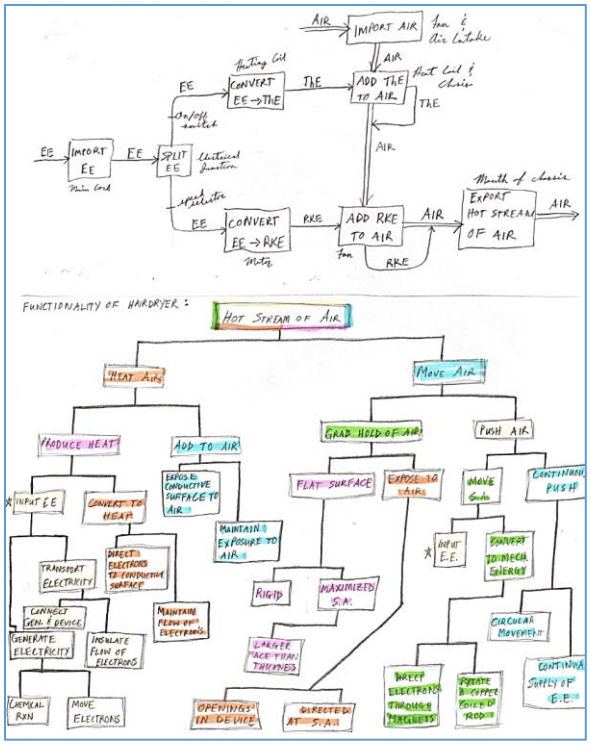

FIGURE 1
FUNCTION MODEL OF A HAIR DRYER (IN-CLASS EXERCISE)

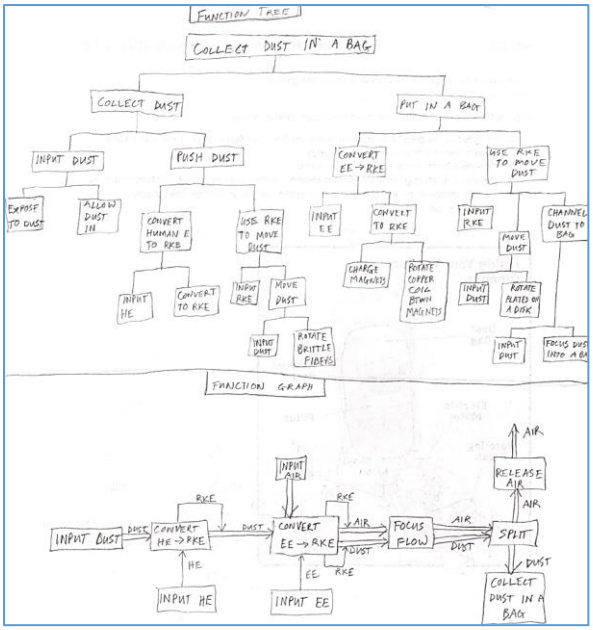

FIGURE 2
FUNCTION MODEL OF A VACUUM CLEANER (HOMEWORK)

II. Entrepreneurial Engineering Project

Because the students came up with the design problems of the entrepreneurial engineering project themselves and they were aware about their projects' uniqueness within the class, they were deeply invested into the project. Thus, the novelty and variety of the products designed and built by the class was higher than the pre-2015 model, where every team built variants of the same product that only varied superficially. The overall quality of the projects were better than the prior model too, possibly due to the greater student morale and more direct involvement of the professor and the TAs in the projects.

The variety of freshman projects in Fall 2015 ranged from shoes for children in remote areas that could power a light bulb at night, to skateboards with regenerative braking, to a ballast for windmills floating in mid-ocean, to the examples shown in FIGURE 3, FIGURE 4, and FIGURE 5. FIGURE 3 shows a wave energy extractor designed for the consumer market – a product that one could buy at a home improvement store to harvest energy from the river waves and power the decorative lights on a deck. FIGURE 4 shows a vaccine carrier that could be mounted on a bike, powered by the biker and the sun simultaneously, and then would maintain a 2 cubic inch volume inside a box at temperatures suitable for storing vaccines, so that they could be delivered to and kept active in remote locations that do not have electricity. FIGURE 5 shows a prototype of a road surface which produces electricity from the thermal difference of the hot asphalt and the cold ground water a few feet underneath. As seen from these examples, the variety of the products, the novelty of their ideas, and the quality of the design and prototypes were achieved at a high level.

FIGURE 3
WAVE ENERGY GENERATOR – BIDIRECTIONAL WIND TURBINE

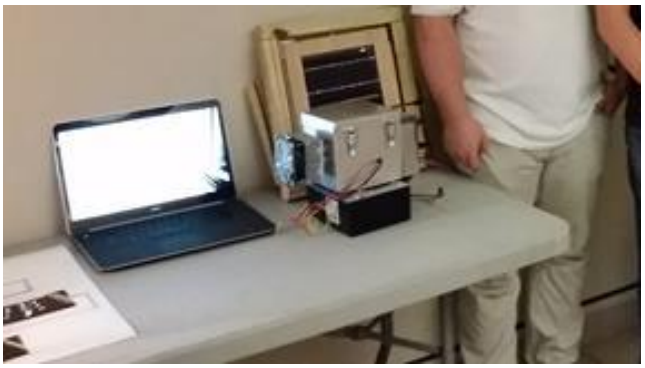

FIGURE 4
HUMAN-SOLAR-POWERED, BIKE MOUNTED, VACCINE DELIVERY SYSTEM

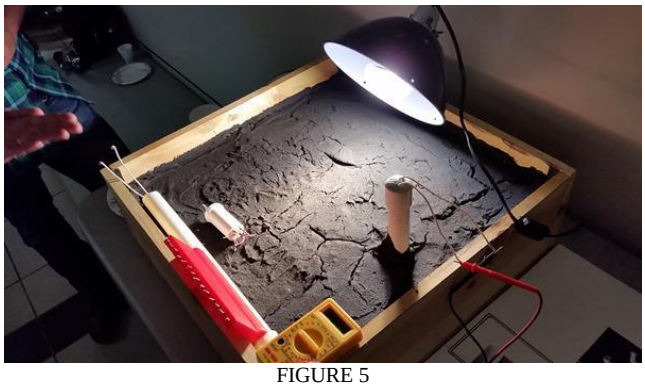

FIGURE 5
ROAD SURFACE THAT PRODUCES ELECTRICITY FROM THE THERMAL DIFFERENCE BETWEEN THE HOT ASPHALT AND THE GROUND WATER TABLE

DISCUSSION AND CLOSURE

This paper presents a case of instilling an entrepreneurial mindset in a freshman-level mechanical engineering course through Project-Based Learning (PBL) and entrepreneurial engineering term projects. A PBL module was used to teach the tools and methods of systematic design and to illustrate the importance of following a systematic, tractable process in design. The PBL module comprised of methods for requirements writing, creative ideation, function modeling and analysis, identification of working principles and working structures, and decision matrix for concept comparison. The PBL approach was generally successful, as evidenced by a large number of high-quality student output produced in post-PBL validation sessions in class and through homework.

The entrepreneurial engineering project was presented to the students as a challenge to identify a problem of social importance and innovate a technical solution to it. The high ambiguity of this project assignment forced student teams to face a multi-objective decision problem, akin to those faced by an entrepreneur in the market. The act of discovering the pain points in various consumer markets related to energy that could be addressed in a semester by the limited skillset and knowledge of the freshmen, and identifying a product opportunity that could address those pain points collectively demanded curiosity, prompted connection building, and encouraged a competitive creation of extraordinary value for stakeholders. This treatment helped the freshmen produce high quality and variety of products.

ACKNOWLEDGMENT

The work reported here was funded by a grant from the Kern Entrepreneurial Engineering Network (KEEN) and the Mechanical & Aerospace Engineering Department at Florida Institute of Technology.

REFERENCES

[1] http://timeline.fit.edu/, accessed on May 21, 2016.
[2] http://www.fit.edu/about/factcard/, accessed on May 21, 2016.
[3] http://www.edutopia.org/project-based-learning, accessed on May 21, 2016.
[4] Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., and Palincsar, A., "Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning," Educational Psychologist, 26(3-4), 1991, 369-398.
[5] Krajcik, J. S., and Blumenfeld, P. C., "Project-Based Learning," The Cambridge Handbook of the Learning Sciences, R. K. Sawyer, ed., Cambridge University Press, Cambridge, MA, 2006.
[6] Thomas, J. W., "A Review of Research on Project-Based Learning," The Autodesk Foundation, San Rafael, California, 2000.
[7] Mills, J. E., and Treagust, D. F., "Engineering Education - Is Problem-Based or Project-Based Learning the Answer?," Australasian Journal of Engineering Education, The Australasian Association for Engineering Education Inc, Australia, 2003.
[8] http://www.merriam-webster.com/dictionary/entrepreneurship, accessed on May 21, 2016.
[9] http://engineeringunleashed.com/keen/em101/, accessed on May 21, 2016.
[10] http://engineeringunleashed.com/, accessed on May 21, 2016.
[11] http://kffdn.org/, accessed on May 21, 2016.
[12] http://engineeringunleashed.com/keen/wp-content/uploads/2016/02/KEEN-Frameworks-2016.pdf, accessed on May 21, 2016.
[13] Hazelrigg, G. A., Systems Engineering: An Approach to Information-Based Design, Prentice Hall Inc., New Jersey, NJ, USA, 1996.
[14] Pahl, G., Beitz, W., Feldhusen, J., and Grote, K. H., Engineering Design: A Systematic Approach, Springer-Verlag London Limited, London, UK, 2007.
[15] Otto, K. N., and Wood, K. L., Product Design Techniques in Reverse Engineering and New Product Development, Prentice Hall, Upper Saddle River, NJ, 2001.
[16] Shah, J., Vargas-Hernandez, N., Summers, J. D., and Kulkarni, S., "Collaborative Sketching (C-Sketch) - an Idea Generation Technique for Engineering Design," Journal of Creative Behavior, 35(3), 2001, 168-198.
[17] Sen, C., Caldwell, B. W., Summers, J. D., and Mocko, G. M., "Evaluation of the Functional Basis using an Information Theoretic Approach," Artificial Intelligence for Engineering Design, Analysis, and Manufacturing, 24(1), 2010, 87-105.
[18] Sen, C., and Summers, J. D., "Physics-Based Reasoning in Conceptual Design using a Formal Representation of Function Structure Graphs," Journal of Computing and Information Science in Engineering, 13(1), 2012, 011008.
[19] Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S., and Wood, K. L., "A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts," Research in Engineering Design, 13(2), 2002, 65-82.
[20] Sen, C., Summers, J. D., and Mocko, G. M., "A Formal Representation of Function Structure Graphs for Computer-Directed Modeling and Conservation-Based Reasoning," ASME Journal of Computing and Information Science in Engineering, JCISE, 13(2), 2012, 021001.

AUTHOR INFORMATION

Chiradeep Sen Assistant Professor of Design, Mechanical & Aerospace Engineering, Florida Institute of Technology, csen@fit.edu
Pierre Larochelle Professor, Mechanical & Aerospace Engineering and Associate Dean, College of Engineering, Florida Institute of Technology, pierrel@fit.edu