AC 2011-124: INTEGRATING INNOVATION INTO ENGINEERING EDUCATION

Matthew Spenko, Illinois Institute of Technology

Matthew Spenko is an assistant professor in the Mechanical, Materials, and Aerospace Department at the Illinois Institute of Technology. Prof. Spenko earned the B.S. degree in Mechanical Engineering from Northwestern University in 1999 and the M.S. and Ph.D. degrees in Mechanical Engineering from Massachusetts Institute of Technology in 2001 and 2005 respectively. He was an Intelligence Community Postdoctoral Scholar in the Center for Design Research, Mechanical Engineering Department, at Stanford University from 2005 to 2007. His research is in the general area of robotics with specific attention to designing for, understanding, and exploiting the dynamics of mobile systems in the context of challenging environments. He focuses on biologically-inspired locomotion, novel vehicle designs, and robot-terrain interaction. He is a member of IEEE and ASME and an associate editor of the Journal of Field Robotics.

Jamal S Yagoobi, Illinois Institute of Technology

Jamal Yagoobi is a faculty member of the Mechanical, Materials and Aerospace Engineering Department at Illinois Institute of Technology.

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Integrating Innovation into Engineering Education

Abstract

In 2009 and 2010, the Mechanical, Materials, and Aerospace Department at the Illinois Institute of Technology held two workshops titled: "Integrating Innovation into Engineering Education." Participants included representatives from NSF, national laboratories, universities, and industry. The focus of the workshops was to understand how to teach innovative thinking at the undergraduate level. Three specific questions were addressed: 1) what defines innovation in the context of engineering; 2) what skill sets are necessary for innovative thinking; and 3) how can educators teach those skill sets in order to foster the innovative thought process. The results of these discussions are presented in this paper.

1 Introduction and Background

In 2009 and 2010, the Mechanical, Materials, and Aerospace Department at the Illinois Institute of Technology held two workshops titled: "Integrating Innovation into Engineering Education." The workshops were part of the Illinois Coalition for Manufacturing Innovation (ICMI), which is sponsored by the Small Business Administration and includes Argonne National Laboratory, Chicagoland Chamber of Commerce, and the Chicago Manufacturing Center. The goals of ICMI are to incorporate innovation education into the engineering curricula, to initiate a series of collaborative projects with small to medium-sized manufacturers, and to work with research institutions to not only facilitate this effort, but also spread its successes nationally. The main goal of the workshops was to investigate how innovative thinking can be taught in undergraduate engineering curricula, with a specific focus on mechanical engineering. Representatives from twelve universities, Argonne National Laboratory, NSF, and industry convened to discuss the topic in small groups followed by a larger discussion with all participants. Note that different organizations were represented each year and that no students were involved in the discussions since the goal was to bring together educators and industry.

After being separated into small groups, participants were asked three questions:

1. What defines innovation in the context of engineering? Specifically, what are the hallmarks of an innovative engineering approach, process, design, or product?
2. What skill sets are necessary for innovative thinking?
3. How can educators teach those skill sets in order to foster the innovative thought process?

The outcomes of these discussions are presented in this paper and can be used as guidelines for developing/modifying curriculum in an effort to emphasize innovative thinking.

2 Discussion

The following is a description of the participants answers to the questions posed above.

2.1 Identifying Innovation in Engineering

All participants agreed that the study of creativity and innovation is important to an undergraduate engineering curriculum. Several key points were made in regards to identifying innovation in the context of engineering. These included the concepts that innovation is an implementation of creativity, that it is inherently transformative (i.e. it addresses a need in some novel way that also brings value), and that it ultimately results in the ability to bypass an engineering trade-off while exhibiting some level of elegance.

For the purposes of an engineering education, the participants concluded that innovation is the implementation of creativity. It is important to recognize that this definition requires an additional step beyond creative thought. Thus, in order to teach innovation, educators must incorporate not only creative thought techniques but also methods to implement ideas in a meaningful manner.

There is an aspect of innovation that is inherently transformative. That is, a creative solution to an engineering problem may simply be an idea that no other person has offered. However, an innovative solution has an additional component—it makes a direct impact or bypasses an engineering tradeoff in an elegant manner. One counter-example of this is the Segway Personal Transporter, which is a product that was hailed by the media as innovative[1,2], but actually lacks innovation as defined by the workshop participants. It was certainly a creative product, nobody had done anything like it before. However, despite the media frenzy, the Segway, although unique and technologically advanced, was *not innovative*—it failed to take into account aspects such as market demand or the national infrastructure (i.e. the Segway was originally marketed as a replacement for walking and most US cities are not pedestrian friendly) and thus was not transformative.

Finally, the panel noted that it is common for "experts" to discount an innovative solution to an engineering problem. In terms of an undergraduate engineering curriculum, one can have a broad view of the term "experts" and simply use it to refer to upperclassmen (juniors and seniors) who have more experience than their freshman and sophomore counterparts. The participants noted that innovation must be taught differently for these two groups of students. Underclassmen tend to be more creative, but their lack of knowledge and experience requires professors to focus the students' creativity into a well structured process that can help the students learn how to implement their ideas. In contrast, upperclassmen have more knowledge, which can both help and hurt the creative aspects of innovation. It can help by giving them reference points from which to build ideas off, but it can also stifle creativity because the students can get caught concentrating on what "does not work" and subsequently they dismiss a solution. Thus, in the latter years of an undergraduate education, professors should focus on methods to maintain creativity and prevent students from concentrating on the negative aspects of an idea.

In conclusion, the workshop participants found that innovation:

1. is the implementation of a creative idea;
2. addresses a need in a novel way;
3. brings inherent value to the problem; and

4. is often discounted by “knowledgeable” people.

2.2 Identifying the Skill Sets Necessary for Innovative Thinking

The workshop participants recognized that there are several key skills that may lead to innovative thinking. Most notably, a student should be open-minded, not afraid of rejection, curious, and passionate. Furthermore, there is a clear role for the “renaissance” engineer who possesses a wide breadth of knowledge but lacks depth. These characteristics are not inherent in all students; however, educators can focus on teaching these skills to increase innovation.

In order to encourage an open mind, educators can provide students with information on how their engineering curriculum fits into a broader context. The participants also noted that the open-minded thought process must be capable of being channeled into a clearly defined, realistic, and understandable goal. This allows students to recognize and then empathize with different viewpoints, which in turn helps students be more creative. Educators can do this by detailing the interconnectivity of engineering and other professions including marketing (understanding consumer needs), law (understanding patents), and government (understanding how regulation impacts the direction of technology).

Diversity is another way to help create an academic environment of open mindedness. Admissions offices in universities have striven to create student bodies that are as diverse as possible. This has a clear impact in classes that involve significant discussion components, such as those taught in the liberal arts. However, engineering courses rarely, if ever, contain significant discussion sections, and thus the benefits of a diverse student body are lost. The participants noted that this needs to change so engineering students can take advantage of learning from their classmates’ skills, experiences, and interests.

A benefit to an open-minded culture is that it makes it easier for students to accept rejection. Naturally, for every innovative engineering solution developed there are numerous solutions that fail. Participants noted how difficult it is for some students to propose ideas because of fear that their idea will be thought poorly of by their classmates and professors. Thus, in order to combat this problem, educators must promote an open-minded environment where students feel safe to fail.

The workshop participants also noted that perhaps the most difficult skill sets to teach are intellectual curiosity and passion, and yet they are both important to innovation. In particular, participants recognized that an innovative idea commonly needs a passionate person to champion the idea in its early stages.

Last, it was recognized that although not necessary, is is often a positive to have a broad set of experiences to facilitate innovation. Thus, “renaissance” engineers can be an important glue that helps bring groups of other engineers together in a successful collaboration. This engineer may not have detailed knowledge of multiple subject matters, but he can serve as a intermediate between other members of the group. Obviously, only a few students can fill this role, but it is important to recognize those who do and cultivate the skill and thought process.

In summary, the workshop concluded that there are five skills associated with innovation:

1. an open mind;
2. no fear of rejection;
3. curiosity;
4. passion; and
5. a breadth of knowledge as opposed to specific and focused knowledge.

2.3 Teaching Innovation

To address how innovation can be taught, participants began with the premise that all engineering students possess some level of creativity and that there are specific and well understood techniques to improve the creative thought process.[3] These techniques can be interspersed in design classes throughout curriculum and would not significantly affect the time spent on other subjects. However, several other ideas were presented that require significantly more effort and resources. These include:

1. the introduction of non-engineering subjects taught to emphasize how engineering relates to business, public policy, psychology (human interaction design), and global competitiveness;
2. effective communication techniques;
3. specialized physical space;
4. case studies;
5. increased use of intramural and extramural competitions; and
6. an overall curriculum change such that innovation is incorporated into the majority of engineering classes.

Each of these ideas was implemented in some form at the universities of the workshop participants and are discussed in detail below.

One suggested method was to introduce non-technical courses into the curriculum. Obviously, free electives and required humanities and social science courses fill this need to a certain extent; however, the workshop participants suggested that this be taken further so that a connection was made between non-technical classes and engineering. That is, it is important to create links between non-technical courses and the engineering thought process in order for the student to understand how non-technical topics (economics, entrepreneurship, business modeling, ethics, political science, psychology, and global competitiveness) affect an engineer's job. For example, an engineer can use a basic knowledge of psychology to learn how to empathize with the end user of a product. This in turn will help the engineer become more creative by understanding how his design is perceived by other people. The downside is that the introduction of non-technical courses is constrained by credit hours. If a department wishes to pursue this option, it must decide what portions of its current curriculum can be condensed or removed while still maintaining ABET accreditation.

A common theme among the workshop participants was the importance of communication in creating an innovative thinker. It was recognized that innovative thinking builds upon the innovation of other people or team members. Several suggestions to implement this included virtual or real collocation, the use of social networking technologies, and an emphasis on visual and tactile prototypes.

To expand on the idea of collocation, many workshop participants stressed the importance of an experimental learning environment to facilitate effective communication. The space must be able to promote prototyping and creativity. This suggestion was based on such spaces being implemented at many of the institutions represented by the workshop participants. A dedicated space helps develop a Confucian model of learning where students learn by doing. Another suggestion was to use this learning environment to teach reverse engineering techniques for underclassmen as a way to understand how other engineers have solved specific design challenges. One particular example used by the University of Notre Dame included having sophomores reverse engineer projects from the previous year's senior-level capstone design course.

Case studies were suggested as a method to promote intellectual curiosity and passion. Participants noted the role of storytelling as a way to increase students interest in a subject. Currently, this is mostly done as small interludes in a lecture setting, but could easily be expanded to become a more formal teaching tool.

Several participants noted that competition drives innovation and creativity. Design competitions can be utilized at all stages of a student's education. Several universities reported including small, weekly or bi-weekly design competitions in their curriculum. Students would typically be required to solve a specific design challenge using limited materials or resources. Specific rewards were found to not be necessary—the pride of winning appeared to be sufficient for students. Barriers to this approach are mostly time-related since fabrication or build time can be substantially more than that spent on typical homework.

The last suggestion made by the workshop participants was to integrate a common theme of innovation throughout the curriculum. Current curricula are commonly segmented into different tracks such as fluid/thermodynamics or dynamics/control. This is in general a useful way to teach because it only requires that the professors who teach in the same track collaborate with each other to ensure continuity among the different classes. However, it would be beneficial to the students if a single theme ran through all classes. The workshop participants did note that there are several barriers to implementing this system including a lack of incentives for the professors as well as logistical difficulties.

In summary, the workshop outlined six key ideas that might be implemented to encourage innovation in an undergraduate engineering curriculum. The panel recognized that there are also several barriers to implementing these ideas such as resource allocation and lack of proper incentives for faculty.

3 Conclusions and Future Work

The two ICMI workshops held in 2009 and 2010 focused on how educators can best implement innovation into an undergraduate engineering education. The workshop participants addressed questions of what innovation is, what characteristics an innovative person has, and how innovation can be taught. Immediate benefits to Argonne National Laboratories and the participants from industry cannot be directly identified, but the results of these workshops can serve as guidelines for educators who are trying to inject a larger emphasis on innovative thinking in their curriculum. The host institution, the Illinois Institute of Technology, will be applying these guidelines in an upcoming (Fall, 2011) new sophomore-level design course titled "Design for Innovation." The course will be required for all mechanical engineering students. Although the class will be open to non-mechanical engineers, it is unlikely that they will participate since most majors at the university have limited sophomore-level free electives. Obviously, any change in the curriculum can pose resistance both among the faculty and the student body. At this point, the faculty has embraced the course and the introduction of the course is based partially on student input asking for more design courses. Future work on this topic will involve evaluating the effectiveness of some of these suggestions after the course is complete.

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