Design in Engineering Education and Practice

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Abstract

This paper reports on a new core graduate course that has been developed for the recently established Department of Engineering Education at Virginia Polytechnic Institute and State University (Virginia Tech). The course is focused on preparing future engineering faculty members and practitioners to teach engineering design as well as how to function more effectively in industry design environments. Material related to theories of student learning and appropriate pedagogical approaches to teaching an open-ended subject such as engineering design are included. Having successfully completed this course, students are able to describe engineering design process and compare and contrast design across engineering and non-engineering disciplines. Students develop a syllabus for a design course in their own discipline, including assignments and projects. They also learn about effective project management and are able to characterize and demonstrate effective means of teaching/coaching/mentoring of various design projects. As future educators, students are able to describe the ABET (Accreditation Board for Engineering and Technology) requirements for design courses (Capstone, etc.), describe and demonstrate various theories of learning and pedagogy, and are able to navigate the course design and approval process. Descriptions of student mentoring of K-12 design teams in the FIRST LEGO® League competition are also provided.

1. Introduction

Design has been described as the epitome of the goal of engineering[1], as it is core to facilitating the creation of new products, processes, software, systems, and organizations through which engineering contributes to society by satisfying its needs and aspirations. Though formal definitions of engineering design vary somewhat, it is commonly agreed that design is a process, a means to an end, that is scientifically based, creative, and most often noble in its purpose as contributions are sought which satisfy human and/or societal needs. Whether the outcome of the process is a system, product, or process, engineering design serves to translate need into concepts which are realizable. Implicitly and often understated, engineering design is also *responsible*; responsible for the impacts, positive and negative, on the world it serves. Engineering design

is responsible for major contributions which have defined our modern world: transportation, medicine, utilities, communication, and agriculture, among many others. Yet, the inceptions of engineering design are also directly responsible for failures which are capable of causing death and destruction: collapsing bridges, chemical leaks, electrical fires, nuclear power accidents, and automobile accidents. Further, and with much attention in recent years, engineering design is held responsible for the impact it has on life-cycle issues such as costs, usability, safety, manufacturability, serviceability, recyclability, sustainability, disposability, and quality; ultimately, determining the success or failure of products and organizations. Indeed, design is considered an issue of national importance[2]. *Good* design practices can be observed, but *how* can the expertise and methodologies employed be captured, transferred, implemented, formalized or improved? *Why* are some people more likely to be good designers? These are just some of the questions that researchers and practitioners have sought to answer.

In engineering education, students (undergraduate and graduate) are often involved as participants in various design projects and work as research team members. As part of their education, students may have received some guidance on how to perform in a team and how to proceed through the design process, though this can vary widely from one engineering discipline to another. However, there is often little or no instruction on how to identify problems and choose appropriate design projects or how to mentor, coach, or assess design projects. Significant needs persist in engineering design education: 1) to research engineering design process pedagogy, 2) to develop methods for proceeding through projects, 3) to develop methods for assessment of student designs, 4) to train students to be more effective team members, and 5) to be more effective facilitators and leaders of industry design teams.

Today's engineering graduates are ill prepared to teach a design course or to function as a facilitator of an industry design team. As engineering graduate students, we were never taught how to teach design. As engineering educators, we have spent many years developing and honing our abilities to create meaningful design projects for our students and coach them through to fruition. As far back as 1992 (13 years ago), Dixon spoke to the need for doctoral programs in design[3]. The time is well overdue for newly minted engineering M.S. and PhDs to have the knowledge of modern design methods, team building, coaching and assessment so that they can be effective design teachers without years of on the job trial and error professional development.

Conducting a search of the ASEE data base from past annual conferences from 1996 to present, one can discover close to 100 papers dealing with teaching engineering design. Most of these papers discuss the introduction and implementation of more effective approaches to teaching design for faculty of particular courses. This body of work has expanded the horizons of design education with many outstanding new avenues of teaching design from hands-on design-build experiences[4] to reverse engineering and dissection laboratories[5] to creativity and communication courses[6]. There have also been advances with numerous service learning[7], industry collaborative[8] and other innovative design projects[9]. While these approaches and activities have made major contributions that have altered the techniques and pedagogy of teaching engineering design available to faculty, there has been little or no work reporting on the education and preparation of *future* design educators.

This paper illuminates an attempt to teach graduate students, our future professoriate, the landscape of design education and how engineering design is practiced in industry, also the various approaches that can be taken to teaching design in a variety of educational environments. The scope of the course is broad to give students the spectrum of activities encountered in design which is by nature interdisciplinary, team-oriented, collaborative, open ended, and possibly distributed geographically. The course should be taught at the graduate level because those students are likely to be interested in the professoriate as a career or in the practicing of design at an advanced level. In addition to the preparation of engineering design educators and practitioners, the course provides three important opportunities for participants, including:

1) Community Outreach
   Students served as mentors to $4^{th}/5^{th}$ grade teams at a nearby elementary school participating in the FIRST LEGO® League design competition[10]. This link with the community has helped students understand the challenges of teaming and mentoring and promotes a personal bond that has given students a sense of purpose and pride, and cultivates professionalism and social responsibility.

2) Interdisciplinary Education
   Engineering design is an interdisciplinary field of great breadth. It is core to all engineering disciplines. Exposure of students to design from a broad perspective and contact with practicing designers enhances their understanding of the importance of cross-discipline integration[11]. This understanding is critical for today's engineers to face the challenges of the 21st century and provide better service to the society at large[12].

3) Integration of Research and Education
   This course is one of the core courses for the recently established Department of Engineering Education at Virginia Tech. Taking full advantage of the advances in design education and practice requires close integration of research and education.

The sections that follow provide a description of the course design, highlights of specific projects, and results and evaluation of the course. Conclusions and future plans are also provided.

2. Course Design

It is our belief that future educators and practitioners must understand engineering design from a process perspective first, prior to focus on specific characteristics and methodologies of a particular field of engineering. As such, an interdisciplinary, rather than discipline specific approach is adopted throughout the course. Moreover, as design is a creative, team-based, problem-solving process, our future teachers and practitioners enrolled in the course are presented with technical science-based methods and tools of analysis and decision-making, as well as non-technical topics such as teaming, project management, communication and writing, theories of student learning and appropriate pedagogical approaches to teaching an open-ended subject such as engineering design. By the end of the course the students design and develop a design course in their own discipline, including their personal approach and philosophy of teaching design, along with learning objectives and outcomes with accompanying syllabus, assignments, projects and case studies. Students are encouraged to be creative and open to innovative ideas in their course design and methods, embracing technical and non-technical topics, stimulating activities, outside collaborators and partnerships.

An overview of the faculty team and guest lectures that supported the Design in Engineering Education and Practice course is provided next. The course learning objectives are then described.

2.1. Faculty Team and Guest Lectures

In its first offering, the course was team taught by Dr. Janis Terpenny and Dr. Richard Goff of the Department of Engineering Education at Virginia Tech. While this course did not require team teaching, each instructor brought unique and complimentary strengths to the course content. Dr. Terpenny is the Co-Director of the NSF e-Design Center and has extensive teaching, advising and research experience in the field of engineering design. Dr. Goff has extensive experience with early design and teaching/advising design for engineering and industrial design students. He has won numerous awards for teaching excellence. Both instructors bring a wealth of industry experience and enthusiasm to invention, innovative teaching methods and learning to the classroom.

Outside guest lecturers from industry and a variety of academic partners provided valuable input and an experience base to inform and expand the course on topics, including:

- How to develop and implement partnerships with small companies for real-world design projects taken on by student design teams,
- The role of product decomposition activities and the benefits of product platforming/family definition in engineering design education,
- Written and oral communication in design as well as strategies for effective assignments,
- Creativity and concept generation in industrial design and architecture,
- Outreach to k-12 student design teams through mentoring,
- Using technology to enable distributed collaborative design teams (domestic and international),
- Environments and fostering innovation and design process in industry,
- Design evaluation and decision support tools, and
- Integrating Universal Design Techniques into instruction environments.

In addition to the above guest lecturers' topics, several lectures were given by the authors. In class design activities were employed and online course research were given as homework. Extensive class discussion on design and course development tools also took place. Some of the topics included:

- Design process[13] (including numerous topics from early through detailed design in customer need/requirements definition, concept generation, evaluation, analysis, and synthesis methods, etc.),
- The House of Quality,
- Literature search on existing design courses,
- Faculty Development Institute online course on Learner Centered Instruction,
- Teaming, personalities, individual learning styles and differences,
- FIRST LEGO® League activities, and
- Communication and design assessment.

2.2. Course Learning Objectives

Design in Engineering Education and Practice is a one-semester 3-credit course. Having successfully completed this course, the student will be able to:

- Describe engineering design process,
- Compare and contrast design across engineering and non-engineering disciplines,
- Develop a syllabus for a design course in their own discipline,
- Develop assignments and projects for a design course,
- Describe effective project management,
- Demonstrate effective means of teaching/coaching/mentoring of various design projects,
- Describe the characteristics of good advising and mentoring,
- Describe the ABET (Accreditation Board for Engineering and Technology) requirements for design courses (Capstone, etc.),
- Participate in a team environment and effectively coach design teams, and
- Describe and demonstrate various theories of learning and pedagogy.

3. Highlights of Projects

This section provides brief highlights of several student projects from the first offering of the Design in Engineering Education and Practice course in the Fall of 2004. The charge given the students was to create a design course in their own discipline complete with syllabus, course goals, learning objectives, design projects and assignments. For each project, the applicable discipline, a brief description and a few bulleted items are provided below. Coincidentally, though not required, all courses were directed toward university undergraduate students.

Biological Systems Engineer
Senior Capstone Design Course

- *Comprehensive Design Project* is a two-course sequence that serves as the capstone experience for Biological Systems Engineering undergraduate students.
- Students experience working in a team environment and they apply the knowledge they have gained in their coursework to a “real-world” problem faced by the private sector.
- This course sequence creates an ideal environment for completing the student’s undergraduate education.
- Students benefit greatly from working with actual design problems that are identified by members of industry or engineering consulting firms.

Mechanical Engineer
Freshman Engineering Assistive Technology Design Course

- Universal design and assistance products
- Ideally groups of five students, with the non-traditional students evenly dispersed
- Can use the lab time, but will also need to work some outside of class
- Assignments will be used to lead the progress
- Thompson Children’s Home
    - Already an established relationship
    - Close to the university
    - Would benefit both sides

Mechanical Engineer
Vehicle Powertrain Design Course for second or third year students

- Design project #1 focuses on developing a competitive performing vehicle with best in class fuel economy using only a conventional powertrain
- The “second half” of the class is dedicated to hybrid vehicle design
- Understanding production hybrid vehicles
- Electric motors, energy storage, and fuel cells are broken into separate classes and modeling assignments – because they are non conventional elements and not generally understood as well

Electrical and Computer Engineer
PIC Microprocessor Applications Design Course for second or third year students

- The term project would have student teams devising a microcontroller application of personal or discipline-specific interest.
- It will seek to implement or improve a specific task, process, or some other commercial application.

Aerospace Engineer
Advanced Vehicle Propulsion System Design Course for senior or graduate level

- Students are required to:
  - Work in a team of 3 students, with a created industry personality
  - Design an engine which can accomplish at least 1 of 4 pre-designed missions. Missions focusing on:
    - Cargo Transport
    - Long Range Subsonic / Supersonic Cruise
    - Low Altitude Dash
    - Air to Air Combat
  - Either develop or gain hold of analysis programs in order to assess their design
  - Use written and oral means to document the design from initial inception to final design

Teaching and Learning
Introduction to Innovation Course: The Engineering Design Process

- Fundamentals of the engineering design process with a semester long student-centered design project. It is intended for students with backgrounds in engineering, business, or industrial design.
- Assignments anticipated:
  - Define five major stages of the engineering design process
  - Discuss key concepts of interdisciplinary team based design
  - Develop historical and contemporary perspectives for technological innovation and design
  - Generate a viable, low cost, design concept and working prototype

4. Results and Evaluation

The diversity of the students contributed greatly to the success of this first course offering. There were women, men and men of color. Several disciplines were represented: mechanical engineering; aerospace engineering; electrical and computer engineering; biological systems engineering; industrial systems engineering; and teaching and learning. All of the participants saw a need to improve their knowledge and abilities to teach and work in the design arena. The students contributed with written reports of their discipline specific design courses as well as oral presentations of these courses. They also were mentors and judges for the FIRST LEGO® League competition. They were evaluated based on the quality of their presence, discussion, presentations, mentoring and written work. Student comments about the course were very positive. They were generally very satisfied with the course and felt that they had received much value. They especially enjoyed the variety of the guest speakers and the depth of the in-class discussion. They also enjoyed the informal, playful and spontaneous nature of the instructors. For example, on one of the last days of class we watched design videos and a video of one of the students who was a contestant on “Who Wants to be a Millionaire”. We also watched a portion of “Dirty Dancing” as one of the instructors was in that film. We believe this open, nurturing, fun-loving, and creative environment for learning was very effective and engaging for the students and instructors, who ultimately learned a lot from a variety of sources and from one another. Clearly students will take this engaging approach into their own design classes.

Reflecting back on three major opportunities offered in the course:

- Community Outreach
- Interdisciplinary Education
- Integration of Research and Education

Community Outreach through the FIRST LEGO® League mentoring of elementary school students was a highlight for the course participants, instructors and the Harding Avenue Elementary School students. The graduate students became mentors of two teams of 4th and 5th graders that would not have been able to participate in the FIRST LEGO® League competitions had they not stepped in. The graduate students gained invaluable experience working with very active, entropic kids. They learned to give them time to burn off energy and then how to focus their attention on the jobs at hand that consisted of designing, programming, and constructing a robot that was required to perform several tasks autonomously. The sense of accomplishment by all parties upon completion was clear.

Interdisciplinary Education was inherent as engineering design was presented as an interdisciplinary field of great breadth that is core to all engineering disciplines. The diversity of the class participants across several disciplines provided excellent opportunities for discussion, comparison and contrast of the different fields represented. As collaboration with Industrial Designers is also required in many industries, exposing the students to the nature and possible contexts of design from industrial designers’ points of view and with practicing designers enhanced their understanding of the importance of the cross-discipline integration of various engineering disciplines and industrial design.

Integration of Research and Education was a highlight of the course unique to many engineering graduate students. As one of the core courses for the recently established Department of Engineering Education at Virginia Tech we took full advantage of the advances in design education and practice by requiring student research and investigation into the state of current design education through the literature, availability of innovative materials on the Internet, and personal contacts and investigations through peers at a variety of institutions.

In the “could be improved” list, one student would have liked to have the final project more well defined and several students expressed desire for more guest lectures and the inclusion of topics such as how to bring industry collaborators into courses and how to foster collaboration across disciplines. Interestingly, all students expressed sadness about the course ending and suggested that the course have a second semester practicum experience where they could implement (teach) the new course they designed with weekly group meetings for mentoring and feedback.

5. Conclusions and Future Plans

In conclusion, we believe that this graduate course on "teaching design" has been well worth the resources and effort that were required. Students are expanding and reinforcing their engineering design education well beyond the traditional engineering graduate disciplines. The educational community will benefit greatly from the knowledge and insights gained by the graduate students taking this course. This course will become part of the core requirements for the M.S. and PhD in Engineering Education.

Our future plans include efforts to expand the participation of students, guest lecturers and collaborators in this course. The lively and extremely valuable class discussions contributed greatly to the direction of the next iteration of the course. One area that will be improved is the navigation of the course design and approval process in a University environment. We also plan to develop this course into an online offering as virtual and distance learning is an excellent way to allow more participation in a course of this type[14].

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