Educating Future Engineers by Learning about Design Processes

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Abstract
Engineers in the near future should have strong analytical skills, practical ingenuity, and creativity. These engineers should also be dynamic, agile, resilient, and flexible; that is, they should be able to adapt. Consistent with this view, this paper presents a specific vision of what these engineers should be able to do in the years ahead to adapt to the ever-changing needs of society and a vision of how design education should adapt as well.

Keywords: engineering design; design education; design processes

According to *The Engineer of 2020* [1], engineers in the near future should have the following attributes that are related closely to design: strong analytical skills (establishing structure, planning, evaluating performance, and aligning outcomes to a desired objective); practical ingenuity (identifying problems and finding solutions); and creativity (based on a broad range of knowledge). These engineers should also be dynamic, agile, resilient, and flexible; that is, they should be able to adapt.

Consistent with this view, this paper presents a specific vision of what these engineers should be able to do in the years ahead to adapt to the ever-changing needs of society and a vision of how design education should adapt as well.

As described in *The Engineer of 2020*, engineers increasingly work in new interdisciplinary fields of endeavor that address organizational challenges and societal issues related to public policy, sustainability, and economic development. Although the challenges will change over time, engineers who can apply essential design skills can help people solve problems even as new technologies replace the old ones. Engineers will not only design products and technical systems but also help design processes and systems that involve people as well as technology. For example, Jenkins [2] described four types of systems engineering problems: (1) create a machine, (2) create a capability, (3) create a strategy, and (4) create a culture.

Indeed, engineers should not view any specific novel technology—or technological innovations in general—as the solution to every problem. When working to solve a problem, engineers, along with the other stakeholders and the public, must evaluate the implications of potential solutions by evaluating whether they are asking the right questions, solving the right problems, avoiding harms to our society and environment, and truly contributing to the common good. The development and application of technology, no matter how useful, should be governed by these bounds, and solutions that don’t involve technology may be the best choices.

To help design diverse solutions for a wide variety of problems, engineers must be able to use a variety of design processes. No single design process will be sufficient for every situation because the quality of existing knowledge, the performance of existing solutions, the uncertainty about the future, the nature of the risks, the consensus of the stakeholders, and many other factors will vary. In some novel problem situations, there may be no obviously appropriate design process, and engineers will have to design the design process by dividing the problem into appropriate subproblems and deciding how to approach each one.

This topic is especially important because many engineers work on design teams, and the members of a team need to work together to carry out the design process. An ad hoc approach to planning the design process will create confusion and increase the risks of project failure (e.g., poor product or system performance and cost and schedule overruns).

Despite the growing need for design process planning skills, existing engineering education programs fail to provide opportunities for engineering students to learn these meta-reasoning skills. Many engineering students learn only standard product and systems development processes [3, 4]. In a typical engineering design course, the students follow the assigned process mechanically because their project deliverables follow the steps in the process.

Educational goals. Design education programs should provide opportunities for students to become adaptive engineers who can design solutions to diverse, complex problems.

In particular, students should be able to do the following:

- Recognize different types of design processes and decision-making contexts.
- Explain why a design process is (or is not) appropriate for a problem situation.
- Choose an appropriate design process for a problem situation.
- Separate a design problem into appropriate subproblems.
- Plan the activities needed to conduct a design process.
- Manage the risk associated with a design process.
- Apply appropriate analysis techniques to evaluate potential solutions to a design problem.
- Design a product, system, or process by using an appropriate design process to develop a feasible, desirable solution to a problem situation.
- Analyze the behavior of a design team to identify the decisions that they made and their design process.
- Evaluate the performance of a design process and recommend improvements.

Vision of design education. To help students achieve these goals, a design education program should consider adopting the following activities in its courses:

- Studying designers: students should observe and analyze designers at work; options include cornerstone and capstone design teams and real-world design processes.
- Multidisciplinary projects: students should do interesting design projects as members of multidisciplinary teams, where the teams include students from majors besides engineering and may include students at universities in other parts of the world.
- Design problem diversity: students should solve various types of design problems: physical products, software, and IoT devices; manufacturing, healthcare, business, and similar processes; structures and infrastructure systems; and unstructured problems.
- Design process diversity: students should learn about and gain experience with different types of design processes, including waterfall, spiral, and problem structuring.
- Making good decisions: students should develop their decision-making and risk management skills throughout their design projects [5].
- Self-directed learning activities that feature autonomy, purpose, and mastery, which increase students' intrinsic motivation to learn [6].

Engineering students need to study design. In other disciplines, students begin by observing the phenomena to be studied, but engineering students are plunged into design (especially in cornerstone design courses) before they've ever seen anyone design. Certainly, engineering students learn about design in cornerstone design courses, but they learn only one process, which is a limited perspective, and they have little opportunity to reflect upon the process and consider alternatives. Observing more experienced students and professional engineers will provide a richer understanding of design. Moreover, this type of activity will allow students to reflect on the many ways that design can be done. Engineering design researchers often study student design teams to learn about design; engineering students should do the same as they begin to become reflective practitioners.

Engineering students need to understand design process options (types of design processes) and how they affect the time and cost of the design process and the quality of the product or system that is generated. These design processes might include (1) waterfall processes similar to the standard product development process (and the processes often used in cornerstone and capstone design courses); (2) spiral processes used in systems engineering and software engineering (sometimes called "agile"); and (3) problem structuring methods for messy, "wicked" problems. Problem structuring methods are suited for addressing poorly defined (unstructured) problems in which multiple actors (stakeholders) have different perspectives, seek widely different and perhaps conflicting interests, and are facing uncertainty [7].

Two programs at the University of Maryland have introduced these types of activities to undergraduate students in engineering and other disciplines. The First-Year Innovation & Research Experience (FIRE) program provides first-year students with research experience. In 2017, twenty-five students began the Designing Innovations track, which focuses on how teams design innovative products and systems. In the first semester, these students worked in teams to solve challenging system design problems and analyzed, described, and compared their design processes. In the second semester, the students will design and conduct experiments in which teams of students and professionals solve challenging system design problems, will analyze, describe, and compare these design processes. The students learn both qualitative techniques (observing and recording subjects, coding activities, and qualitative data analysis) and quantitative techniques (quantitative data analysis, machine learning, text mining, and programming).

The University of Maryland QUEST Honors Program, which includes students from engineering, business, and science, offers a course called "Design and Innovation in Silicon Valley." The students in this course study multiple design processes from mechanical design, software engineering, and systems engineering. They read noteworthy references and, during a trip to California at spring break, meet with subject matter experts at multiple firms in San Francisco and Silicon Valley to gather information about the firms' product and software development processes. After they return, each student writes a report that describes one firm's design process in detail and compares that process with the other firms' processes and the ones described in the literature. In particular, the students analyze how the processes include customer input and feedback, the techniques used for testing, the types of design reviews, and the frequency of new releases.

The vision described here does not dismiss the need for engineers to respond to the actual situation as the design process unfolds, for design is clearly a type of situated action [8]. It merely seeks to introduce a more explicit discussion of design process planning so that future engineers can analyze a design situation, consider design process alternatives, and choose the one most likely to succeed before beginning. This will not only help them use their design skills to create an effective product or system but also increase their ability to adapt to the ever-changing needs of society so that they can become the Engineers of 2020.

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Biography

Jeffrey W. Herrmann is a professor at the University of Maryland, where he holds a joint appointment with the Department of Mechanical Engineering and the Institute for Systems Research. He is the Academic Director of the University of Maryland Quality Enhancement Systems and Teams (QUEST) Honors Program. He is a member of the Design Society, IIE, ASME, INFORMS, and ASEE. His textbook *Engineering Decision Making and Risk Management* won the 2016 IIE/Joint Publishers Book of the Year Award.