Educated Human Judgement: Design and Analysis: Where to probe, and where to pass-by?

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We can use Engineering Design to learn Engineering Analysis by packaging Engineering Concepts and introducing them early in the curriculum; by teaching technology functionality from a Design perspective; and by tailoring the right balance between Design and Analysis for Students' projects in upper level classes.

I decided to write this essay in the Design Library on my campus. Around me are books on "Engineered Wood," "Time and Framing in Photography," "Design Magic: Meet Disney's Creative Team," and "The Dymaxion Car." In the library, there are models of buildings of students' work from what seems to be architecture studios, Fig. 1. While not an architecture student myself, I have always enjoyed reading about architecture. At one point, I ventured into learning how to transfer ideas from architecture education to my practice of engineering education. I observed an architecture class and attended several showcases to understand how architects are trained to become designers, artists, planners, social activists and critical thinkers, all at once. In this essay I draw a picture of a curriculum that centers on Design in the engineering curriculum, and advocates for Analysis as one way to support decisions in Design.

1. *The problem*

It seems to be an agreed upon characterization that engineering students emerge from a four-year curriculum well-trained in the specific, the well-known, and the measurable of engineering knowledge. They are not trained to synthesize knowledge for the new, yet-to-built, and the uncertain of situations. It *is* difficult to train anyone on combining specialized concepts to new problems. In a speech at Purdue University, former NASA Administrator (2005-2009) described the problem as follows:

> "Sadly, many students have been led to believe that engineering science is engineering! In a curriculum of 120 or more credits leading to a bachelor's degree in a branch of engineering, the typical student is required to take one, or maybe two, courses in design. Everything else, aside from general-education requirements, focuses on the analysis, rather than the creation, of engineered objects. Graduate education often has no design orientation at all. So, engineering as taught really deals with only a part of engineering as it is practiced." (Griffin, 2007)

2. *Critical decisions*

However, engineering educators, as well as practitioners of the profession, need to make a choice between two distinctive interpretation of Engineering Design: (1) the popular choice of solving well-structured problems; or (2) the innovative choice that combines analytical thinking with creative synthesis to create, and take advantage of, opportunities in the society. In order to make the choice, there will be at least three critical decisions that have to be made.

2.1 Critical decision I—Problem solving or Design. Problem solving characterizes engineering problems as structured, well-defined problems. Consider, for example, optimizing the flow rate in a refrigeration cycle, or defining the parameters for a communication link between two locations. Such problems can be traced to "hard systems thinking" and have standardized techniques to be solved (Checkland, 2000). In contrast, Design in engineering involves giant leaps to reach beyond what already exists. It does not follow standardized processes, and, instead, seeks negotiating conflicting interests (Holt, J.; and Radcliffe, D.; and Schoorl, D., 1985).

2.2 Critical decision II—Rigor or relevance. With efforts to re-thinking engineering education (see, for example, Seely (1999)), a question arises as to whether such efforts are made to let engineering education in academia match as much as possible the professional engineering practice, or to be independent of it. Consider the topic of thermodynamics: From history, we learn that thermodynamics started to become modern science after Sadi Carnot published a book that outlined the relationship between heat, power, energy and engine efficiency. Early experimentation with steam engines took place in the 1600's; Carnot's book, however, *Reflections on the Motive Power of Fire*, was published in 1824 (Carnot, 1824). In today's mechanical engineering curriculum, one wonders how many students actually experience the opportunity of going through a complete cycle of conceiving of an engine, designing it, implementing it, and operating it. A critical decision has to be made to carefully analyze the relevant concepts in engineering sciences so that they become *tools* for the Designer, and not things that encompass all that which represent engineering.

2.3 Critical decision III—Assessment or reflection. Embracing the notion that Design is central to engineering education requires expanding the horizon to how students reflect on their attitudes and behaviors to problems involving situations, circumstances and other stakeholders. At the institutional level, Schön argued that the "scholarship of discovery" has dominated the modern research universities in the US. He also argued that the "scholarship of integration or synthesis," upon which design thinking is largely dependent, cannot thrive in an "institution exclusively dedicated to technical rationality" (Schön, 1995, p. 34). Schön's reflective practice represents a departure from Herbert Simon's *The Sciences of the Artificial* in which he stretched the limit calling for the professional schools to teach what he called the "Science of Design" to be "a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process" (Simon, 1996, p. 113). A critical decision has to be made as to whether students' work should be assessed for technical precision or for the ability to reflect on action.

3. *So, how would it look like?*

I prefer the vision of Schön for the reflective practitioner. At the same time, I wish I had experienced going through the full-cycle of conceiving-designing-implementing-operating a system, from its infancy to its deployment (see Crawley, E.; Malmqvist, J.; Ostlund, S.; Brodeur, D. (2007)). I sketch below one way for me to use Engineering Design to learn Engineering Analysis. It involves:

- **Design Project (every semester/year):** I like to experience a semester-long Design challenge, which later evolves into a one-year project in the Junior and Senior years. I wish to have the Design project aligned with *Theory Classes* which I hope to be introduced at the Junior and Senior years. Design projects should center on a human need. They should progress in depth and sophistication, serving as cornerstones for critical development and view of the world. They should accumulate into a cohesive portfolio that represents a critical stance on how I, as a student, view societal issues that involve a technical dimension. Projects should encourage educating the reflective practitioner.
- **Representation and Context (Freshman):** I imagine a curriculum where I am taught at the Freshman level ways to describe systems in both *Mathematical and Visual Representations*. In addition, I wish to be introduced to issues of *Historical and Societal Contexts* which can be blended with how we represent systems.
- **Engineering Concepts (Sophomore)**: I wish to be introduced to distilled-to-its-essence engineering concepts, in my Sophomore year. *Concepts* are a collection of abstract ideas, that can be applied as they exist, without necessarily understanding the theory behind them (black boxes). An example could be: a collection of Structures Concepts, or Chemical Processes.
- **Technology of Function (Junior):** I wish to understand the "build-up" of modern technology, as a collection of packaged black boxes. For example, instead of learning electromagnetics (which I should have learned at the Sophomore level), I wish to understand how cell phone communication works.
- **Product/System Analysis (Senior):** At this level, I wish to be challenged to dissect a piece of technology, articulating eloquently the *Technical and Social* decisions behind its Design (see Dym, C.; Agogino, A.; Eris, O.; Frey, D.; and Leifer, L. (2005)).
- **Theory Electives (Junior and Senior):** I wish to decide, with advice, a sequence of detailed *Theory Classes* that cut across disciplines and that align with my on-going Design Projects, at those years. Ideally, the instructor may tailor the content to the Design Challenges. Only at the third year, I start to equip my Design decisions with necessary *Mathematical Analysis*.

4. *Images of an Engineer*

As I make myself ready to depart the library, I pick Henry Petroski's *Remaking the World*. In this book, Petroski starts by showing the picture, Fig. 2, of Einstein with Steinmetz (Petroski, 1999).

Karl August Rudolf Steinmetz was born in Breslau, Germany in 1865. He earned a doctorate in mathematics, and immigrated to America in 1889. He joined the General Electric (GE) Company, and drew upon his strong mathematical physics background to solve practical problems for which he brought patents for GE. One of his many contributions in electrical engineering was the hysteresis loss law that is used to calculate power loss in transformers. He was also the one who developed and introduced the use of complex numbers for calculations involving alternating current (AC). Aside from his ingenuity, Steinmetz was an eccentric person, the combination of the two made his mention easy to the newspapers and popular magazines. With this publicity, lots of photos of Steinmetz in different life arenas were distributed. One of the most famous ones is this picture of him with Albert Einstein:

> "The father of relativity stands tall, formal, and self-assured beside the short and stooping, hand-in-pocket and smoking, rumpled and scowling figure who looks to be, ambivalently, both leaning toward the famous scientist and pushing him back with an elbow … In it [Steinmetz] seems complemented only by his standing next to a Nobel laureate, as if the engineer needed a scientist to lean upon. The photograph's semiotics reinforce the stereotype of the engineer vis-à-vis the scientist, of engineering versus science. In this picture the great engineer Steinmetz is reduced to a caricature of himself; by implication, his achievement is diminished relative to that of the giant he stands beside." (pp. 8-9)

The photo turned out to be fabricated from a group photo that was taken in the occasion of a Radio Cooperation of America-sponsored demonstration of transoceanic telegraph transmission at New Brunswick, New Jersey in 1921. Petroski continued that,

> "The Einstein-Steinmetz photo is actually as false as are its implications for the relationship between science and engineering. The great scientist and the great engineer never did pose one-on-one, as they are presented in this photo." (p, 9)

The key to my proposal is to introduce Analysis to the student as a universe of possible models that only provide approximation to reality. The students will still have to develop educated human judgment, to know which models to recall and which to pass-by to serve their decisions.

Fig. 1. A model in the Design Library.

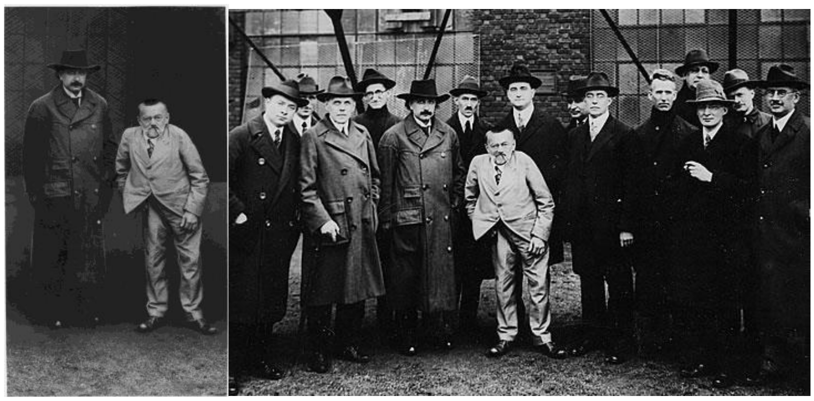

Fig. 2. On the left is the fabricated photo of Steinmetz and Einstein. On the right is the original photo.

Fig. 3. Commercial from Mercedes-Benz showing the analytical and the creative sides of the brain.

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