Square Peg, Round Hole, Good Engineering

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You see things; and you say, "Why?" But I dream things that never were; and I say "Why not?"

—George Bernard Shaw

Attractive things work better.

— Donald Norman

Introduction

A dominant theme across current educational discourse, both in the popular media and in more academic writing, is that STEM education (Science, Technology, Engineering and Math) in America is in a state of crisis. For every article calling for the production of 21st century engineers – able and equipped to tackle the problems of society today – there are numerous articles expressing grave concern for the field. This concern is two-fold. First, it is argued that American STEM education does not produce the sheer number of qualified, technically competent professionals necessary for our ever-expanding and global economy (BHEF, 2011; Maloney, 2007). Second, it is suggested that, even those who are graduating, often lack the quality and competence to meet emerging challenges (Chen, 2009). The challenges for engineers and other STEM professionals in the next decade range from topics of solar energy to urban infrastructure from virtual reality to sustainability. With our growing population, changing climate, and mass consumption, there exist very real and daunting problems to be addressed. And science and technology will *have* to play a crucial role in coming up with these solutions. As Dr. Cherry Murray argues, "This century will call on all fields to address the most compelling issues on the planet – call this 'convergence' – and engineering will underpin them all" (Murray, 2011).

Despite this apparent agreement on the existence of a crisis there is little consensus on how to move forward: in other words, how to create a new educational paradigm or approach that can best prepare our STEM graduates to meet these challenges. We believe that to successfully meet these challenges, engineering education must change. It must adopt competencies and skills associated not just with standard conventions of the discipline, but with creativity, flexibility, transference across disciplines, and openness to the new. We argue that one way to better understand how such changes can be brought about involves studying successful engineers and inventors, and through that to identify strategies and approaches that worked for *them*. In this series we have previously highlighted examples from mathematicians and scientists who were inspired by music (Mishra, Henriksen, & The Deep-Play Research Group, 2012). In this article we look towards two innovative engineers/designers, Nikola Tesla and Steve Jobs, for inspiration.

Tesla and Jobs

Nikola Tesla was one of the most prolific engineers of the early 20th century. Often overshadowed by his contemporary, Thomas Edison, in the popular imagination, Tesla played an integral role in the adoption of alternating current (AC) electricity, the invention of radio communication, advancements in x-ray technology, and countless other advancements of science and technology. At the turn of the 20th century, at a time was just beginning to understand how electricity, radio waves, and energy could each be harnessed, Tesla tinkered with wireless telegraphy and electrical currents.

Fast forward to the turn of the 21st century, where Steve Jobs and his team tinkered with Gorilla Glass and Bluetooth connectivity to develop some of the most coveted and iconic technologies of today, from the first generation iPod with the click-wheel, to the sleek screen of the iPad. For these two iconic engineers, both the existing technologies and the foreseeable potential for new technologies could not have been in more different places. And yet, only twelve years separate their lives. Such is the rapid pace of change.

Both Jobs and Tesla were revolutionary thinkers, pushing the boundaries of knowledge and experimentation, and few would question their contributions to science and technology. But more importantly, for us, both Jobs and Tesla demonstrated a set of skills and abilities not usually associated with that of the conventionally proficient engineer or scientist. They displayed an ability to conceptualize, design, and think holistically about engineering problems. For Tesla and Jobs, the answers weren't found in a new computational equation or theorem. Instead, the answers were identified through a completely new approach, rich with not only engineering prowess but also broad-minded and cross-disciplinary creative competencies.

For instance, Tesla's brilliance came not just from his knowledge of engineering, there is no doubt of his skills in that arena, but rather from his unique ability to conceptualize and think visually about an apparatus or a problem. As he said,

> My method is different. I do not rush into actual work. When I get a new idea, I start at once building it up in my imagination, and make improvements and operate the device in my mind…When I have gone so far as to embody everything in my invention, every possible improvement I can think of, and when I see no fault anywhere, I put into concrete form the final product of my brain (Tesla, 2007, p. 19).

As Miller (1996) notes, the importance of visual imagination in Tesla's work, and in the history of great scientific thought overall, cannot (and should not) be ignored. Miller goes on to argue that the most talented people in STEM disciplines have developed competencies for creative thinking, which they carry out through mental and visual imagery (Miller, 1996). For Tesla, great engineering was heavily reliant on a strong conceptual understanding, complemented by the ability to imagine things visually, to design and consider the entirety of a concept with imagery, *before ever dealing with equations*. Again quoting Tesla,

> Before I put a sketch on paper, the whole idea is worked out mentally. In my mind I change the construction, make improvements, and even operate the device. Without ever having drawn a sketch I can give the measurements of all parts to workmen, and when completed all these parts will fit, just as certainly as though I had made the actual drawings" (Tesla quoted in O'Neill, p. 257).

Tesla was openly critical of fellow engineers who over emphasized equations and theorems. Such an approach diminishes an idea's real-world applicability, as he noted, "Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation, and eventually build a structure which has no relation to reality" (Belohlavek & Wagner, p.81).

Steve Jobs, in contrast to Tesla, has often not been regarded as being a top-notch engineer. He was considered a bit of a showman, more concerned with the aesthetics of the objects he designed than being involved with the actual engineering. That said, one thing does join these two individuals. Just as Tesla brought his strong unique personal ability to the engineering design task, Steve Jobs brought his own unique sensibility to the design of devices and technologies, and his contribution to the global market, popular culture, and technology is undeniable. While many companies profited from the technological boom of the late 20th century and early 21st century, Apple stood out because of the "aesthetic" quality of their products – which became so deeply embedded in the culture and lives of consumers that they have developed a tremendous and devoted cult-like following. From the iPad to iPhone to iMac, from the Apple store to the Apple website, Apple sought to create a user experience rich with design, simplicity, intuitiveness, and advanced technology.

For Jobs, engineering a new product wasn't simply the pursuit of a new additive feature (the dreaded "featuritis" that plagues most software and hardware). Instead, it was about finding innovation that improved the device, as a whole. And while Apple products are often described as "beautiful" or "elegant", design was much more intentional for Jobs. As Jobs stated,

> Design is a funny word. Some people think design means how it looks. But of course, if you dig deeper, it's really how it works. The design of the Mac wasn't what it looked like, although that was part of it. Primarily, it was how it worked. To design something really well, you have to get it. You have to really "grok" what it's all about. It takes a passionate commitment to really thoroughly understand something, chew it up, not just quickly swallow it. Most people don't take the time to do that" (Wolf, 1996).

Jobs famously detailed, during a Stanford commencement address, how his appreciation of design, and through that Apple's famous aesthetic, emerged from his own interest being piqued by sitting in on a calligraphy course in college. Ironically, it was a course he attended after having withdrawn from the university itself. This primary experience led to others and culminated in the Macintosh being the first computer to offer real fonts and typefaces. This concern for type and design was not just an add-on but rather integral to the Apple experience—a concern that the company emphasizes to this day. The key point here is that Jobs integrated a diverse and unique array of competencies and experiences into his own engineering, and that helped him to design in ways that were unique, creative, and aesthetic. Said differently and more simply, for Jobs, engineering problems weren't only solved through equations or modifications. Emphasizing the value of varied experiences in design he said,

> A lot of people in our industry haven't had very diverse experiences. So they don't have enough dots to connect, and they end up with very linear solutions without a broad perspective on the problem. The broader one's understanding of the human experience, the better design we will have (Wolf, 1996).

We must add that this focus on cross-disciplinary thinking, and creativity is not to downplay the technical skills and knowledge that engineers (or Tesla or Jobs for that matter) bring to the complex craft of design and engineering. Creativity in engineering cannot happen without deep knowledge of mathematics, engineering or other technical fields. But the important point for us as educators is to understand that technical skills and knowledge while necessary are not sufficient, in and of themselves, to engender creative solutions.

Tesla and Jobs are not alone in having abilities that spanned disciplines of ways of thinking. Countless examples of talented thinkers in science and mathematics reveal that creative individuals tend to think this way (Root-Bernstein, 1999). For example, Mlodinow (2003) points out that the great physicist Richard Feymann's ability to solve problems in physics came not just from knowledge of equations, but from Feymann's imaginative approach, in which physicists must "wave our hands, use analogies with simpler systems, draw pictures, and make plausible guesses" (Mlodinow, 2003, p. 61). This was Feynman's trademark style – building not just on pure mathematics, but through the focused use of a powerful and vivid imagination paired with knowledge of the discipline. Feynman also spoke of the role of beauty in scientific ideation, suggesting, for instance, that one of the main reasons for Descartes seeking to understand the physics of rainbows had as much to do with the inherent beauty of rainbows as it had to do with the pleasure of figuring things out (Mlodinow, 2003).

Of course any insights that Feynman arrived at needed to be represented mathematically just as Tesla's visualizations and Jobs' aesthetic concerns needed to lead to functional machines and products. All that said, it is important to note that creation was driven not by an equation but rather by a deeper connection between different disciplinary approaches. *Engineering and problem solving for such skilled and successful thinkers most notably comes from a wider matrix of imagination, abilities, skills, and curiosities or cultivated interests in other disciplines.*

We argue such boundary crossing thinking is what needed today. Tesla and Jobs demonstrated the kinds of skills, knowledge, and ability to transfer ideas between domains that modern engineers, we argue, ought to adopt to meet the demands of the present and future. Given the engineering challenges of today, such broad-minded cognitive abilities are needed in STEM fields and in STEM education more so than ever before. But in order for modern engineers or scientists to develop these faculties, STEM educators must intentionally incorporate pedagogy to support this shift in engineering education.

Re-Thinking the Engineering Focus:

Herb Simon, in his classic work *The sciences of the artificial* argued that around two or three decades after World War II, engineering education in specific (and professional education in general) changed drastically. Essentially, he argued that,

> Engineering schools gradually became schools of physics and mathematics; medical schools became schools of biological science; business schools became schools of finite mathematics. The use of adjectives like "applied" concealed, but did not change, the fact. It simply meant that in the professional schools those topics were selected from mathematics and the natural sciences for emphasis, which were thought to be most nearly relevant to professional practice (Simon, 1996, p. 111)

According to Simon this had to do with a range of reasons but most primarily because these institutions "hankered after academic responsibility" and chose to go with topics that were "intellectually tough, analytic, formalizable and teachable" (Simon, 1996, p. 112). This was in contrast to topics and approaches, such as real-world design, that were (considered to be) "intellectually soft, intuitive, informal, and cookbooky" (Simon, 1996, p. 112).

These factors are now shifting as engineering and STEM have become sectors of education under deep scrutiny. From elementary to secondary and beyond, countless articles and op-ed's call for strengthened inter-disciplinary studies, heightened humanistic and inter-personal skill development, and greater integration of proper technology to fit the curriculum. Creative thought processes and transferrable knowledge across disciplines are considered an increased necessity for achievement in our multifaceted and interdependent society (Florida, 2002; Freedman, 2007).

A strong engineering/STEM education must certainly have a focus on pedagogy of calculus, thermodynamics, metallurgy, and other traditional engineering disciplines. But it is also necessary to heighten and advance skills in the humanities, design, social sciences, and promote abilities like creativity, and abstract and critical thinking. This is analogous to Dr. Murray's comment, "The engineers of the future will likely be 'T-shaped thinkers,' deep in one field but able to work across all fields and communicate well" (Murray, 2011).

We suggest that the most relevant and applicable framework for blending and promoting these needs and goals in STEM disciplines is trans-disciplinary thinking or what we have called (in)disciplined learning (see other articles by the Deep-Play Research Group in previous issues and Mishra, Koehler & Henriksen, 2011 for more details). With a focus on creativity, and thinking across disciplines, we suggest that this framework offers a good fit for promoting divergent and effective thinking abilities.

Our discussion of Tesla and Jobs demonstrates that it's not always possible to tell exactly *where* a talented creative individual's inspiration and abilities may come from, because inspiration varies by individual, their interests, background, skills and talent. For Tesla, it happened to be his own unique interest and ability for visual thinking and abstraction, and his desire to work in more practical and "real-world" settings and applications (unlike some of his solely "equation-focused" contemporaries that he bemoaned). Jobs drew inspiration through other varied topics and experiences he encountered in life and in the world around him (his calligraphy interest was just one of many unique interests). Tesla and Jobs demonstrated exceptional brilliance in the content knowledge of their respective disciplines. It was their secondary/tertiary skills, however, that distinctly defined their work.

Conclusion

Though where and how the creative spark will strike is difficult to predict, we do know that ideas do not usually emerge solely from within their own STEM discipline. In contrast, the evidence indicates that they are often created and enhanced through outside disciplines, interests, and experiences, which is then fully worked through and realized in the context of strong core disciplinary knowledge (STEM/engineering, etc). We can also say that they will emerge through creative cognition, from divergent and cross-disciplinary sources and experiences. Given this, it is important that we provide a range of broad and varied educational experiences to students in engineering and STEM fields. It is in fact essential that such curricula not be one-sided or solely focused in STEM content alone. Rather we argue that a certain amount of richly varied liberal arts learning should be woven into the curricula of such subjects. Engineers, and other individuals in fields of science, technology, engineering and mathematics, must be able to pull from tertiary subjects, disciplines, skills, and experiences to greatly enhance their own problem solving and creative abilities. As we begin to understand the science and engineering demands of our world in this 21st century, it becomes clear that students in these fields must have the kinds of thoughtful and varied learning experiences that enable them to think richly and broadly, both within, outside of, and across the disciplines.

Note: *The Deep-Play Research group at the college of education at Michigan State University includes: Punya Mishra, Danah Henriksen, Kristen Kereluik, Laura Terry, Chris Fahnoe and Colin Terry.*

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