Innovation and Creativity:
What Are They and Can They Be Taught?

by

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Executive Summary. "Innovation" and "creativity" are nearly always mentioned today as key to the future. However, there are so many conflicting definitions and uses of these words that many conversations about this topic often result in confusion and conflict. After establishing definitions and a brief review of reasons why these topics are especially important today, a framework for understanding the call for substantial change in higher education to address the growing need for creativity and innovation is presented. Sustainable large-scale innovations always involve feasibility, viability, and desirability simultaneously. However, widespread and early specialization in higher education may work against this. Engineers and scientists spend most of their education studying the world through the lens of "feasibility," whereas business professionals and economists focus through the lens of "viability." Those studying liberal arts subjects such as humanities, art, and psychology focus on human needs and motivations at the root of "desirability." The implications of this are explored in some detail. Finally, the challenge of teaching creativity and innovation to individual students is taken up. We conclude that, regardless of the amount of latent talent, student achievement and competence in creativity and innovation can be developed, through deliberate curricular design and appropriate experiential learning.

Background. There are many studies of creativity, and it is not the purpose of this short paper to provide an exhaustive summary of the research to date. Of the many definitions, one attributed to Sir Ken Robinson[1] is most appropriate for our purposes: creativity is the process of generating original ideas and insights that have value. He and other psychologists note that all humans have multiple capacities for creativity. Furthermore, creativity is less about genetic inheritance than it is about appropriate environment. While some individuals may seem to have a greater genetic capacity than others, most people have a degree of creative capacity in several domains. Finally, any individual can be creative in one environment, but not in another. Environmental factors (fear of failure, perfectionism, need for peer acceptance, resource limitations, time pressure, etc.) may play an important role in enhancing or suppressing creative behavior.

However, Howard Gardner[2] has proposed that too often the public assumes creativity is the domain solely of the arts—and not other in fields. He points out that creativity exists in all fields. He also points out that all individuals have the capacity for creative work, not just the few who are especially gifted in a particular way. To observe and recognize creativity requires a context or domain and an expert in a recognized field. Creative work must be judged creative by experts in a field in comparison with the recognized traditional accomplishments of others in the same field. As a result, creative work sometimes goes unrecognized for many years after the creator has passed away.

Another dimension to creativity is the extent to which it involves incremental change, or revolutionary reconceptualization. Reconceptualization usually requires fundamentally new insight, a reframing that often results in analogies with other domains or similar challenges in different contexts.

Variation on a theme and improvisation are frequent approaches or techniques for the development of new ideas. There is some evidence[3] (in the music domain) that improvisation is a key skill in developing the ability to create variation on a theme extemporaneously. Contemporary jazz involves

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1 Robinson, Ken, Out of Our Minds: Learning to be Creative, Capstone Publishing, Sussex UK (2001); also TED talk, *Do Schools Kill Creativity?,* Feb. 2006 (most popular TED talk ever recorded—viewed more than 38 million times).

2 Gardner, Howard, Creating Minds: An Anatomy of Creativity Seen Through the Lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi, Basic Books, New York (2011).

3 Zagorski, Nick, *Music on the Mind*, **Hopkins Medicine** Spring/Summer 2008.

extemporaneous improvisation whereas performance of classical music is carefully scripted in advance. Often a jazz musician is unable to script in advance the music that s/he produces because it is largely produced extemporaneously in response to the musical ideas of others on stage at the same time. This is similar to the common skill of carrying on an extemporaneous conversation with a friend. You cannot predict in advance what you will say, because it depends on what your friend says, and vice versa.

Charles Limb at Johns Hopkins School of Medicine has measured the brain action of musicians in an fMRI machine while playing classical or jazz music[3]. His results show that improvisation requires silencing that portion of the brain that is responsible for self-censoring and inhibition. Apparently, improvisation requires a state of mind where the musician is comfortable in allowing the free flow of self-expressive ideas, without too much effort at perfecting them first. It is not hard to see why stage fright or excessive "fear of failure" play a large role in suppressing the ability to improvise[4].

In general, creativity uses parts of the brain that are distinct from those that are used for analysis and detailed comparative work. Of course, a balance is needed to produce the best result, and achieving this requires the right environment, coaching, and practice. It is very likely that creativity in other domains follows a similar pattern.

Innovation. The Oxford English Dictionary (OED) provides several definitions for the word *innovation*, including: (1) the introduction of novelties; the alteration of what is established by the introduction of new elements or forms; (2) a change made in the nature or fashion of anything; something newly introduced; a novel practice, method, etc., and (3) the action of introducing a new product into the market; a product newly brought on to the market, among several others.

References for this third definition trace back to the famous economist Joseph A. Schumpeter[5] whose view of a dynamic economy where new ideas and products replace older ones through a continual process of "creative destruction" provides one of the foundations for understanding free markets. A more modern reference for this definition is J.A. Allen who said[6] "*Innovation is the bringing of an invention into **widespread**, practical use… Invention may thus be construed as the first stage of the much more extensive and complex total process of innovation." (emphasis added)*

I will focus on this third definition of innovation for the purpose of this paper, because it frames the issue in very large societal terms that help provide a framework for examining the structure of higher education on the same societal scale. However, it is important to note that many others use to good purpose a more generic definition of innovation that is closer to the first two definitions in the OED with applications in the process of new product design and development, and does not involve widespread application or transforming many lives.

To differentiate these two concepts of innovation, I will use *Innovation* to represent the widespread application of original ideas and insights to transform the way many people live. In this sense, a really profound *Innovation* changes the way people live so profoundly that few people can remember life before it was introduced. On the other hand, I will use *innovation* to represent the more generic introduction of a novel idea, similar to Allen's explanation of invention as the first stage of a more extensive process.

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[4] Since I am naturally a bit introverted and shy, I was extremely nervous when making professional presentations at national meetings when I was younger. My strategy then was to make 3" x 5" cards and write out all the key ideas in advance then attempt to memorize them while practicing in front of a mirror. It was a terrible strategy—stage fright would inevitably overwhelm me during the talk, and my ability to go forward depended entirely on my ability to remember the key phrases I had memorized. The result was frequently freezing up in front of the audience. I still have traumatic memories of this! Many people have similar traumatic memories of piano recitals as children, when they forget the notes midstream and just froze up as a result. Improvisation is more robust and effective, but uncertain.

[5] Schumpeter, Joseph A., Capitalism, Socialism and Democracy, London: Routledge 1942.

[6] Allen, J.A., Scientific Innovation & Industrial Prosperity 1967.

A good illustration of *Innovation* is described in the book A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives[7]. This book traces the introduction of major engineering *Innovations* through the twentieth century, including:

Electrification
Automobile
Airplane
Water Supply and Distribution
Electronics
Radio and Television
Agricultural Mechanization
Computers
Telephony
Air Conditioning and Refrigeration
Highways
Spacecraft
Internet
Imaging
Household Appliances
Health Technologies
Petroleum and Petrochemical Technologies
Lasers and Fiber Optics
Nuclear Technologies
High Performance Materials

Each of the major *Innovations* described in this book are not simply successful new products, they also represent revolutionary industrial processes that transformed society at large. For example, few people today can remember what life was like before the widespread availability of electricity and clean drinking water. Life has been transformed in America and elsewhere because of the widespread impact of the technological innovations outlined above.

The Driving Force for Grand Challenges of the 21st Century. As described in the next few paragraphs, the need for *Innovation* has never in human history been more urgent. The challenges we face now are global in scale with unprecedented complexity. One underlying cause for this is the rapid growth in global human population which is arguably a consequence of the technological *Innovations* of the 20th century.

Shown in Figure 1 is a graph of global human population throughout all of human history. The graph is remarkable for several reasons. In about 1930, global population reached two billion for the first time. Since then, human population has skyrocketed. The technological achievements cited above and spread to other nations have played a major role in enabling such rapid population growth. However, the growth is so sudden and profound that no aspect of human existence in the next century is likely to remain unaffected by this phenomenon. Population biologists report that similar explosive population growth in other species is often followed by extinction.

[7] Constable, George, and Somerville, Bob, A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives, Washington, DC: Joseph Henry Press (an imprint of the National Academies Press)

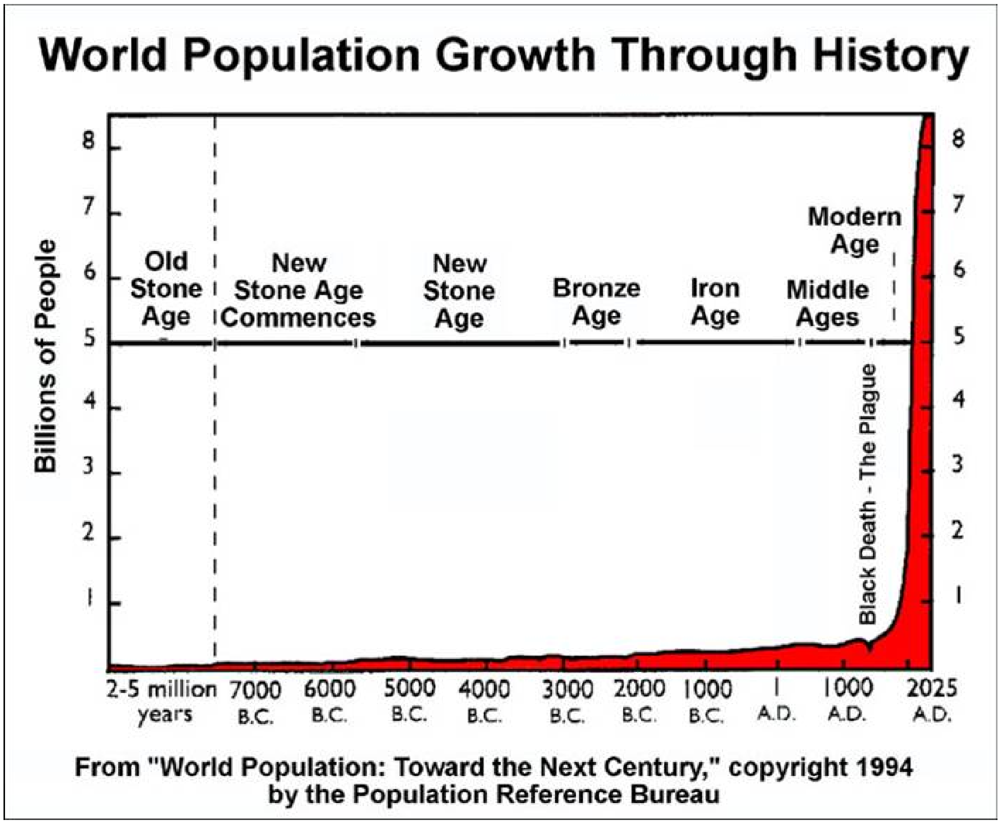

Figure 1 – World Population Growth Throughout History

In 2008, the U.S. National Academy of Engineering (NAE) released a study of the Grand Challenges[8] of the 21st century. The fourteen challenges identified by a blue ribbon panel of experts fall into four major categories: global sustainability, security, health and enhancing life as the population continues to grow—while the resources of the planet do not. The population curve in Fig. 1 underlies all of these challenges creating unprecedented complexity and interdependence. These challenges, in an era of rapid global population growth, require approaches that are fundamentally new—crossing boundaries, including disciplines, time zones and political boundaries—and requiring unprecedented global collaboration and cooperation.

Global population pressures and the reality of the Grand Challenges mean our ability to learn, adapt, and cooperate on a global scale are our best hope for survival. As a result, our ability to collaborate has never been more important, and education will play a key role in producing innovators who can take on these challenges!

Is Our Educational System Up to the Challenge? The changes implied by the population graph are very recent and very rapid, raising many questions. For example, in an era of such rapid change, how useful will the knowledge and methods learned in the past be in approaching the rapidly evolving challenges ahead? What will be the useful "shelf life" of knowledge learned today? Could it be that creativity might become as important as knowledge in the years ahead? Learning to learn adaptively and rapidly, improvise effortlessly, collaborate in multidisciplinary teams, build consensus quickly, and manage the process of change could become the most important objectives of education. These questions are relevant across all of undergraduate education, not just engineering education.

[8] http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=02152008

In contrast, higher education today is largely based on a model developed several hundred years ago, when the challenges were different. In particular, universities today are organized into specialized academic departments and academic degree programs with modular courses taught by experts. These experts are almost always located together by academic discipline in buildings that promote high levels of specialization while simultaneously discouraging interaction with people from very different backgrounds. As a result, faculty members with different disciplinary backgrounds rarely have lunch together or collaborate on complex problems outside their discipline. The academy seems to place relatively little value on attempts to make sense of large, complex interdisciplinary problems[9].

Furthermore, the intense focus on publishable specialized research as the pinnacle of academic achievement discourages faculty members from devoting time to developing courses that are integrative and coherent in presenting a useful overview of knowledge. For example, it is surprisingly difficult to find faculty members who are able to devote the heart of their work to providing a coherent overview of U.S. history for undergraduates. This is because the subject is so mature that the imperative of constantly identifying something new and unique to publish in respected academic journals discourages spending much time on such tasks. Instead, the opportunities are much better to publish a history of a narrow but obscure small subgroup of people living in a narrow time frame in a specific geographic region. The result is often a department of historians that is comprised of experts in narrow but disparate specialties, with very few who are interested and competent at providing the broad sweep of coherent ideas that make sense of history—especially for undergraduates. Of course, this principle is true of almost all academic disciplines, not just history.

When properly done, an integrative and coherent history course could help a student rapidly make sense of world events in a way that is somewhat similar to providing a picture of the finished puzzle when attempting to assemble the hundreds of unfamiliar parts (specialized courses) of an academic jigsaw puzzle.

The problem with the current organization is that it clearly emphasizes fragmentation and narrow specialization. One unintended consequence is that this creates barriers to integrative thinking and the development of new insights by analogy across disciplines.

Innovation as the Intersection of Feasibility, Viability, and Desirability. A familiar mental framework for learning the art of product design is the observation that all successful innovations (both *Innovations* and *innovations*) are simultaneously feasible (because nothing happens in the real world that isn't consistent with the laws of nature), and viable (because unless it is available at an attractive price it won't sell), and also desirable (because unless people choose it freely among available alternatives, it won't be accepted)[10]. There are many examples of innovative ideas that are feasible, but not viable; other examples are feasible and viable, but not desirable, etc. Only when all three occur simultaneously will an innovation take hold and spread.

This may be represented in a Venn diagram, as in Figure 2. The blue circle represents the universe of concepts that are feasible. The green circle represents the universe of viable concepts. The red circle represents the universe of desirable concepts. The intersection of all three represents the space for potential innovations.

[9] Nobel Prize winning physicist Murray Gellman, in addressing this concern, identified what he called the need to take a "crude look at the whole" (CLAW). "*People must therefore get away from the idea that serious work is restricted to beating to death a well-defined problem in a narrow discipline, while broadly integrative thinking is relegated to cocktail parties. In academic life, bureaucracies, and elsewhere the task of integration is insufficiently respected*." (The Quark and the Jaguar: Adventures in the Simple and the Complex, 1995, p. 346)

[10] David Kelley, co-founder of IDEO corporation, and founder of the d.school at Stanford University.

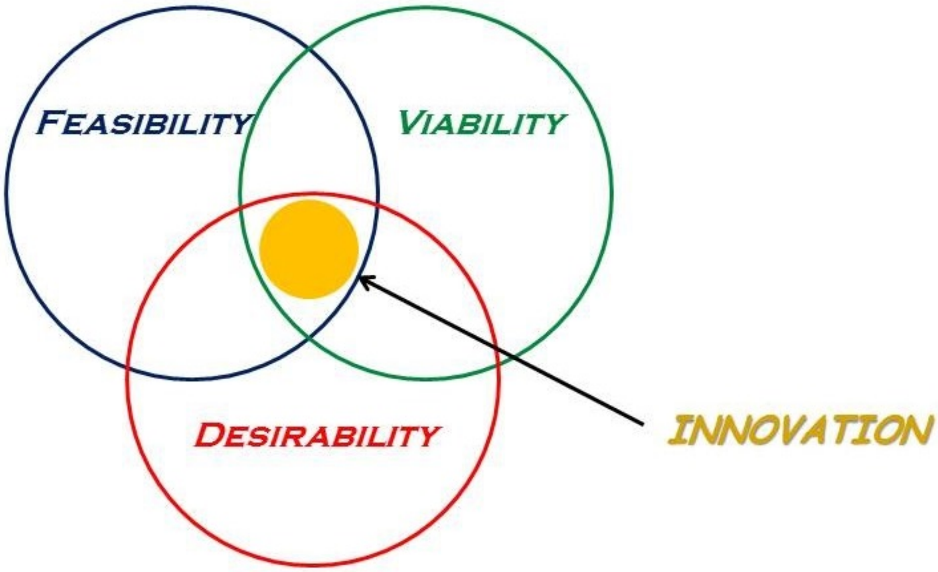

Figure 2 – Innovation as the Intersection of Feasibility, Viability, and Desirability

The important observation here is that the thinking necessary to develop successful innovations is integrative across all three of these domains. While there will always be a need for specialists in each of the three domains, the architect of any innovation must have a clear mental picture of the intersection of all three to enable the innovation to take hold. This perspective requires exposure to integrative and multidisciplinary environments.

It is also noteworthy that the diagram also identifies other subdomains, such as feasible and desirable, but not viable. Similarly, another subdomain is feasible—but neither viable nor desirable (just in case science). Of course, the boundaries of these circles are constantly changing, so what is not desirable today may become desirable in the future, and vice versa.

On the other hand, it is striking that the physical layout of most major university campuses deliberately locates the three circles far away from each other, thereby discouraging interaction. For example, the engineering and science "quad" on the campus is often located together to enable the engineers and scientists to interact conveniently. Similarly, the business school assembles the faculty needed to teach the courses in those disciplines in buildings that are located together in a separate business school on the campus, for the same reason: to enable the specialized business faculty to collaborate more conveniently. Finally, the arts, humanities and social sciences faculty are located together in yet a different region of the campus. This is schematically depicted in Figure 3.

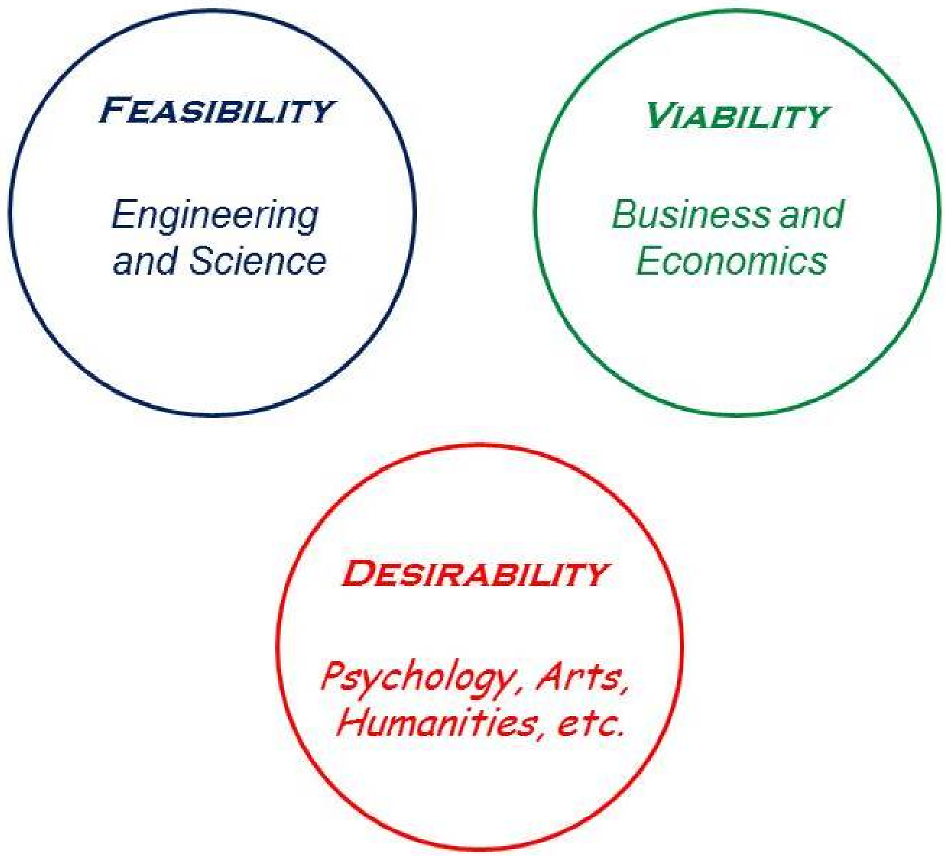

Figure 3 – Schematic Representation of a Campus Map Illustrating the Segregation of Faculty Academic Disciplines

The unintended consequence of this campus master plan is that it reinforces disciplinary specialization at the expense of interdisciplinary collaboration. It is rare to find faculty members located in academic departments identified by sub-discipline who are successful at establishing strong working and social relationships with others in different disciplines[11].

To compound the situation, within each circle, an internal culture frequently develops that is the result of the absence of other voices and points of view. For example, within the Engineering and Science circle, all the faculty teach courses that are focused in some general way on the problem of feasibility. That is, every course addresses some aspect of the question: what is possible relative to what we know today about the natural laws and mathematics. In fact, to obtain an ABET accredited engineering degree, approximately three-fourths of all the credit hours taken by an engineering student must come from within this circle[12]. The absence of other questions often leads to a lack of awareness or appreciation for the

[11] I have frequently encountered senior faculty members on university campuses that have spent decades at the same university, but never even visited the adjacent building on campus—let alone spent time across campus with faculty members from a completely different field. This problem is well-known in university administrations, and forms part of the motivation for creating “maker spaces” that are not “owned” by any discipline. The goal is to draw faculty and students from a variety of disciplines into the same space to discuss problems at the interface of the traditional academic disciplines.

[12] It is noteworthy that current efforts to change the requirements for ABET accreditation would worsen this situation, rather than improve it. They would weaken the efforts to expose all engineering students to the viewpoints of viability and desirability. Furthermore, the current situation in other countries is generally even worse than it is in the U.S. with few requirements for broadening the education beyond science and technology.

importance of other questions, such as the viability of various business or economic systems, which is the focus of most activity within the green circle on campus. In the red circle, where in the problems of human needs and desires are addressed, the questions are much different. For example, questions like "what is the nature of truth?" or "what is the nature of love?" These are the fundamental questions that animate all human activity, yet they are not usually addressed with the tools of natural science and mathematics or business accounting and management.

It is precisely for this reason that the faculty at Olin College are not organized into groups or departments by academic discipline. They are located together in the same building, where a physicist may have an office adjacent to a historian, and an electrical engineer may have an office adjacent to a musician or a mathematician. It is hard to over-emphasize the impact of this arrangement on the resulting interdisciplinary culture and the high level of interaction between faculty that results. The nature of the conversations that take place here everyday is qualitatively different than it is in more traditional institutions, creating daily collisions between world views and personalities, and creating pressure for a holistic, interdisciplinary and integrative understanding of the world. This is exactly the type of learning environment that enhances the widespread conversation about the intersections between feasibility, viability, and desirability.

Can Creativity and Innovation be Taught? This question is ageless and has concerned educators and business leaders alike. There are several related questions: can musicians be educated, or are they born? Can artists be trained, or are they born? Can entrepreneurs be trained and developed, or must they be born for the task? While undergraduate teaching is focused on *innovation* in order to introduce young people to the field and build foundational attitudes and skills, it also provides the foundation for *Innovation* at the highest level when applied to NAE Grand Challenges by experienced innovators.

One of the more detailed and persuasive investigations of these questions is presented in a recent book by Tony Wagner, Creating Innovators: The Making of Young People Who Will Change the World[13]. Tony researched the personal history and background of many different successful innovators from a wide variety of fields to look for patterns. He found that their histories followed the pattern of Play, Passion, and Purpose. Early in their lives, they were raised by parents and teachers who encouraged unstructured play. This curiosity driven phase in their lives naturally resulted in their developing self-directed learning and discovering one or more passions, which then led to some obsessive time commitments as they mastered the skills needed in their chosen activity. Later, as they matured, they found intrinsic motivation centered on a purpose which enabled them to apply their expertise in ways that made a difference for many others and resulted in *innovation*. Tony is convinced that certain learning environments are essential to creating innovators. Experiential learning and self-directed learning with projects as a focus are central to these environments.

A completely different contribution to this challenge is provided by Sanjoy Mahajan in his recent book, The Art of Insight in Science and Engineering. While not specifically focused on teaching creativity and innovation in the broad sense, this book outlines methods of thinking and estimating that result in new insights that are fundamental to deep understanding. As he says in the preface[14]: "*Science and engineering, our modern ways of understanding and altering the world, are said to be about accuracy and precision. Yet we best master the complexity of our world by cultivating insight rather than precision. We need insight because our minds are but a small part of the world. An insight unifies fragments of knowledge into a compact picture that fits in our minds…"* He goes on to explain that in order to develop useful new insight, it is necessary to suppress rigor in the analytical sense. Once again, we encounter the need to use a different area of the brain that looks for qualitative patterns rather than following detailed rules.

[13] Wagner, Tony, Creating Innovators: The Making of Young People Who Will Change the World, Scribner, 2015.
[14] Mahajan, Sanjoy, The Art of Insight in Science and Engineering: Mastering Complexity, Cambridge, MA: MIT Press 2014.

One of the most successful, informative, and persuasive experts in the teaching of creativity and innovation in higher education is Tina Seelig of Stanford University. She has been teaching this subject at Stanford for many years and is a personal source of insight and inspiration for me. Her first book[15] provided many new insights in this area for me. Her deeply rooted "can do" attitude in any situation and her endless array of practical examples of flexible thinking and surprising unorthodox solutions to many puzzles are very persuasive. Many of the examples taken from her course at Stanford are particularly enlightening. You can easily see how students develop their own can do attitude after exceeding their own expectations several times in succession, and then go on to develop an entrepreneurial mindset.

Her latest book[16] provides a structured approach to leading students through this field while developing their attitudes and skills in bringing their own ideas to reality. As she points out, the foundational step in learning to be more creative and innovative is attitudinal. The prerequisite is an **entrepreneurial mindset** that enables you to see opportunities rather than challenges, a mindset of plenty rather than scarcity[17]. Next is the development of a set of learning methods and tools that can be developed by experience with a series of challenging examples. Seelig describes this in another book as follows[18]: *"Creativity can be enhanced by honing your ability to observe and learn, by connecting and combining ideas, by reframing problems, and by moving beyond the first right answers. You can boost your creative output by building habitats that foster problem solving, crafting environments that support the generation of new ideas, building teams that are optimized for innovation, and contributing to a culture that encourages experimentation."*

Finally, Seelig has provided a useful roadmap for moving from inspiration to implementation. This is the subject of her most recent book[16] that is centered on the notion of developing the skills of the entrepreneur in a very specific sense:

Entrepreneurs do much more than imaginable with much less than seems possible[19].

The framework provided by Seelig is in the form of a closed cycle. The four components of the cycle include Imagination (engage and envision), Creativity (motivate and experiment), Innovation (focus and reframe), and Entrepreneurship (persist and inspire). The cycle is closed, so following Entrepreneurship is a return to Imagination.

Of course there are other pedagogical approaches to teaching or enhancing creativity and innovation, but they all involve attitudinal dimensions and experiential learning. This material requires that you use different portions of the brain than the dominant analytical subjects that form the core of all natural science and engineering material.

[15] Seelig, Tina, What I Wish I Knew When I Was 20: A Crash Course in Making Your Place in the World, HarperOne, 2009.
[16] Seelig, Tina, InsightOut: Get Ideas Out of Your Head and Into the World, HarperOne, 2015.
[17] Not every student arrives with an entrepreneurial mindset. Depending on their history, some may have come from an environment where the obstacles to personal success were overwhelming and they were conditioned to believe that they cannot succeed. This situation takes some intervention to overcome. For example, repeated personal experience in exceeding their own expectations on a challenging project that they care about can often plant a seed of hope in their mind. Then reinforcement by peers and a passion to make a positive difference can often turn this around.
[18] Seelig, Tina, inGenious: A Crash Course on Creativity, HarperOne, 2015.
[19] Slogan painted on the wall at the Stanford Technology Ventures Program at Stanford University.

Questions for discussion:

1. How does the discussion and definition of innovation presented in the paper compare with your own understanding and experience?

2. Do you accept the proposition that innovation can be taught? If not, is there a specific aspect of innovation that you are not sure can be taught?

3. Can you think of an example of *Innovation* that is based primarily on viability or business models rather than feasibility within engineering?

4. Can you think of an example of *Innovation* that is based primarily on desirability or human need or passion, without either a dominant feasibility or viability component?

5. How might we effectively integrate creative problem solving into our educational system so that students master the ability to innovate while learning other skills, given the necessity to spend 75% of their time studying math and science?