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# Creativity and Innovation as Part of the Civil Engineering BOK

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## Abstract

This paper contends that the imminent review of the Civil Engineering Body of Knowledge (CEBOK) should include consideration of adding explicit treatment of creativity and innovation knowledge, skills, and attitudes (KSAs). Some reasons offered for this change are: maintaining U.S. global leadership, enhancing national security, stimulating organizational vitality, enjoying the satisfaction of doing what has not been done, and practicing effective stewardship with the superior abilities of engineering students to enable them to achieve even more professional success and significance.

The paper explores whether or not creativity/innovation are already adequately included or implicit in the CEBOK, already addressed by ABET, already in CE education programs, and/or already in the Engineer Intern experience. The conclusion is largely negative, that is, the CEBOK and ABET give minimal attention to creativity/innovation; creativity/innovation receive minimal to moderate emphasis in most undergraduate CE programs and when they do it is mostly in the last year; and, while there is considerable talk in the CE practice world about creativity/innovation, there is very little commitment to it including during engineering internships.

The paper then turns to ways to strengthen the presence of creativity/innovation in the CEBOK. Options explored include a new outcome and a creativity/innovation theme. Finally, the discussion offers some tactics for fitting creativity/innovation into an already full curriculum and a strategy that would incorporate many of those tactics.

All of the preceding is offered with the hope that it will stimulate thinking about creativity/innovation as ASCE moves toward the next CEBOK, or amendments to the existing version.



**Keywords** – biology of learning, brain, Civil Engineering Body of Knowledge, CEBOK, co-curricular, conceptual age, create, creative, creativity, curriculum, Engineer Intern, extra-curricular, innovate, innovative, innovation, knowledge age, knowledge-skills-attitudes, KSA, mini-survey, neuroscience, outcome, Raise the Bar, rubric, strategy, tactics


## Introduction

The Civil Engineering Body of Knowledge (CEBOK) is defined[1] as "the necessary depth and breadth of knowledge, skills, and attitudes required of an individual entering the practice of civil engineering at the professional level in the 21st century." The premise of this paper is that, going forward, the CEBOK should include creativity/innovation knowledge, skills, and attitudes (KSAs).

The reasons for this premise are presented elsewhere[2,3,4] and summarized here. Very briefly, creativity/innovation will be increasingly important for U.S. engineers because of forces such as the Grand Challenges for Engineering; the coming of the Conceptual Age, Opportunity Age, and Wicked Problems Age; maintaining U.S. global leadership and enhancing national security; stimulating organizational vitality; practicing better stewardship with aspiring engineers and their intellectual gifts; and the satisfaction of serving the public by doing what has not been done. In addition to those driving forces, a clear commitment to creativity-innovation in civil engineering education might enhance the discipline's attractiveness to more of the best and brightest young people.

## Creativity and Innovation Defined and Illustrated

### Definitions

While researching creativity/innovation in recent years, I found many definitions of the nouns creativity and innovation and the related verbs, create and innovate. My hope was to find some commonality among the definitions and then I would distill out the essence of each. However, that was not to be because the definitions are "all over the place." Accordingly, for the purpose of this paper, I offer these definitions:

- **Create:** Originate, make, or cause to come into existence an entirely new concept, principle, outcome, or object
- **Innovate:** Make something new by purposefully combining different existing principles, ideas, and knowledge

These definitions were influenced by similar ones offered by engineer and educator consultant Ned Herrmann,[5] teacher and consultant John Kao,[6] consultant Gerard I. Nierenberg,[7] and engineering educators George C. Beakley, Donovan L. Evans, and John B. Keats.[8] These authors collectively suggest that innovate and create differ by degree of originality. While innovation is, in effect, "integrative and aspirational" (Kao) and "grounded in already-invented products or processes" (Herrmann), creativity is "grounded in originality" (Herrmann) and "coming up with something [completely] new" (Nierenberg).

### Examples

As an example of **creativity,** consider Velcro,[9,10] which was invented in 1948 by Swiss electrical engineer George de Mestral. This hook-and-loop fastener is made of Teflon loops and polyester hooks. It was inspired by de Mestral's study of why cockleburs (seeds) stuck to his clothes and on his dog's fur after returning from a hunting trip.

For an example of **innovation,** consider Johannes Guttenberg's development of the reusable-type printing press which he used to begin printing books in the 1450s. He borrowed from woodblock printing, which had been used for eleven centuries in China; weapon and coin forging which went back to Roman times; and the screw press used by winemakers and olive oil producers and for processing linen.[11,12,13]

## Aren't Creativity/Innovation Already in the CEBOK?

### Review of the Rubric

The "Body of Knowledge Outcome Rubric" (Appendix I in the CEBOK report[1]) presents up to six levels of cognitive achievement based on Bloom's Taxonomy for 24 Fundamental, Technical, and Professional Outcomes. In only one case does "create" appear within levels of cognitive achievement associated with the CEBOK.

That exception is Outcome 15, Technical Specialization, where for the "portion of the CEBOK fulfilled through the master's degree or equivalent," also referred to as M/30, the rubric states "Design a complex system or process or **create** new knowledge or technologies in a traditional or emerging advanced specialized technical area appropriate to civil engineering." Variations on "create," such as "creative" or "creativity" and "innovation," or variations on it, do not appear in the rubric.

### Review of "Explanations of Outcomes"

A search of "Explanations of Outcomes" (Appendix J in the CEBOK report[1]) finds a few references to "creativity" and/or "innovation" or variations on them. The search is described in detail in Appendix A of this paper. The words creation, creative (twice), innovative, created, create (twice), and creativity appear. The use of these words is supplemental or incidental, in that they are not part of a strong creativity/innovation theme, with one possible exception.

In outcome 9, Design, "Creative" is used in the discussion of the level of cognitive development to be "fulfilled through the bachelor's degree," also called B, as in "Fostering **creative** knowledge in students prepares them to handle a future of increasing complexity that relies on a multidisciplinary approach to problems."

### Summary

The short answer to the question "Aren't Creativity/Innovation Already in the CEBOK?" is "very little." The longer qualified answer observes that "creative" appears in just one rubric statement that being the M/30 for Outcome 15, Technical Specialization. In addition, "creative" and variations on it along with "innovative" appear eight times in a mostly supplemental or incidental manner in the outcome discussions.

Given that the CEBOK includes 24 outcomes, that the discussion of the outcomes requires 41 pages in the CEBOK report, and that creativity or innovation appear in the rubric of only one outcome and in the discussions of only five outcomes, I conclude that the report gives minimal attention to creativity/innovation. It does not present creativity/innovation as an essential element of the CEBOK.

## Aren't Creativity/Innovation Implicit in the CEBOK?

Some may argue that creativity and innovation are so integral to the study and practice of engineering that there is no need to explicitly mention them in the CEBOK. I agree that the words “create” and “engineer” are linguistically intertwined. As engineers, we are creators (and innovators) by virtue of our profession’s history and name. To engineer is to create![14]

However, I reject the view that creativity-innovation are clearly understood to be part of the CEBOK. Experience suggests that if a major "it," whatever "it" is, is not explicitly mentioned in expectations "it" doesn't get attention. For example, if creativity/innovation are not explicitly and strongly discussed in the CEBOK they will not be widely considered by faculty in program design and execution or by practitioners in supporting their Engineer Interns.

## Aren't Creativity/Innovation in the EAC/ABET General Criteria or CE Program Criteria?

Consider the minimums established for all engineering baccalaureate programs as described in Criteria 3 (Student Outcomes) and 5 (Curriculum) and included in ABET’s *Criteria for Accrediting Engineering Programs Effective for Reviews During the 2015-2016 Accreditation Cycle.* “Creativity,” “innovation,” or variations on them do not appear in Criterion 3. That absence fails to encourage a creativity/innovation outcome but it does not, because the criterion is a minimum, prohibit such an outcome.

Review of Criterion 5 reveals one use of “creative” as in “The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application.” While it makes only minor mention of being creative, Criterion 5 does not prevent including a robust creativity/innovation element in a program.

Focusing on civil engineering, Program Criteria for Civil and Similarly Named Engineering Programs as published in the previously noted ABET document do not mention creativity or innovation or any variations on them. This absence is one reason that creativity/innovation receive little to moderate explicit attention in CE programs as indicated by subsequent sections of this paper. However, going forward and maybe as a result of re-examining the CEBOK, the civil engineering discipline could use its Program Criteria to encourage inclusion of creativity/innovation in CE programs.

## Aren't Creativity/Innovation Already in CE Education Programs?

A purpose of the CEBOK and, more broadly, ASCE's Raise the Bar (RTB) is to improve the formal education and Engineer Intern experience of civil engineers. Therefore, if creativity-innovation are already included in formal education and pre-licensure experience there is no pressing need to include them in the CEBOK. Let’s consider CE programs, that is, curricula and co- and extra-curricular elements.

## Personal View

My 12 years full-time experience as an engineering instructor through dean and eight years as a half-time professor and associate professor lead me to conclude that creativity/ innovation receive minimal to moderate emphasis in most undergraduate CE education programs and when they do it is mostly in the last year. While I have been away from university teaching for about 15 years I have had on-going contact with academia and believe that the situation has not significantly changed.

## Mini-Survey of Educators

In order to pursue further the extent to which creativity/innovation are included in CE programs, I conducted a mini-survey by personally contacting via email 33 faculty I know who have first-hand knowledge of CE and similar programs (e.g., environmental). The short survey instrument, which was structured around four topics and sent in early December 2014, is included as Appendix B. As indicated in the instrument, each potential respondent was assured that their name and that of their institution would remain confidential. Caveat: Reference to courses in the first two questions does not mean that I was advocating creativity/innovation courses.

I received 18 replies. Results of the mini-survey appear in Appendix C and the essentials may be summarized as follows:

- Less than half of the programs have a course or a major portion of a course that explicitly strives to help students be more creative/innovative

- The vast majority of the preceding courses or major portions of courses occur in the senior year

- In slightly less than half of the programs the majority of faculty who teach engineering courses specifically and systematically strive to help their students be more creative/innovative

- In slightly less than half of the programs essentially all students participate in co-curricular or extra-curricular activities that help them be more creative/innovative

- Responses to the "what would you change" question collectively called for more attention to creativity/innovation and cited ways to do so such as having more faculty and other resources

Each question invited and generated many optional responses some of which were selected as being representative and are included in Appendix B to illustrate the wide range of views. The comments suggest that a highly varied and rich mix of insightful viewpoints are likely to surface if creativity/innovation is explored in the next round of CEBOK discussions.

Given the small sample and the moderate response rate, the mini-survey cannot be confidently extrapolated to all U.S. civil engineering programs. Nevertheless, it provides some insight into the role of creativity/innovation in those programs and may stimulate a more thorough survey effort as part of ASCE's upcoming review of the CEBOK.

## Published Views of Some Educators

The mini-survey and, more broadly, my views of CE education programs aside, consider the thoughts of some others:

- In the 1980s, engineering educator Richard Felder[15] observed "It would seem to be our responsibility to produce some creative engineers – or least not to extinguish the creative spark in our students." Commenting on the use of creativity and innovation enhancement methods in engineering education, Felder wrote "these techniques must be introduced throughout the curriculum and not relegated to elective courses on problem solving." His rationale is that these methods should "come to be thought of as routinely-applied tools of the engineer's trade."

- More bluntly and more recently, instructor Edward Allen[16] said "I have seen again and again civil engineering students who were bright-eyed and enthusiastic as freshmen turned into dull, defeated calculation drudges by four years of math only courses in engineering." A bit strong, perhaps, but might a little less stress on mathematics, science, and analysis and a little more attention to design, including explicit treatment of creativity/innovation, help to attract more young people to the study of civil engineering and engage and retain more of those who do select that discipline?

- According to several engineering educators[17] deferring design, and more specifically, creativity/innovation, until the end of the education program may cause these two problems. First, students lose interest in engineering. Young people who were drawn to engineering because they view it as being design-oriented may lack the motivation to persist in programs that appear to be analytically-oriented. Second, having been immersed in left-brain studies for three plus years and then being asked to also draw heavily on the right-brain -- a different mode of thinking -- may be difficult. Multi-year emphasis on analysis may impair students' creative-innovation abilities.

- Regarding the possibility of creativity/innovation being impaired by the most common engineering education model, consider a recent engineering college study.[18] While this very specific study probably proves very little it should cause us to think, discuss, and experiment in a similar fashion. The study's purpose was to "…provide insights into the research question of whether freshman undergraduate engineering students can be more innovative than seniors." Student teams were challenged to design a "next-generation alarm clock" and analyze the results for "originality and technical feasibility."

Conclusion: “Freshman-level students generate designs with higher levels of originality than their senior-level counterparts, without sacrificing feasibility from a manufacturing and design perspective.” This occurred even though the seniors were more advanced in technical and drafting knowledge and skills. As might be expected, the authors recommended more studies. For example, they suggested determining the types of classes and pedagogical techniques that enhance creativity/innovation and considering changing curricula to more effectively promote students’ creative/innovative abilities throughout their undergraduate education.

- Engineering professor Richard McCuen[19] addresses our creative-innovative mind set, or lack thereof, by offering this thought: “The attitude that creative thinking is fun, but unnecessary to solve today’s problems, needs to be replaced with the attitude that creative thinking is an essential problem-solving tool…”

- “It is surprising how little emphasis is placed on imagination, creativity, and design within the standard engineering curriculum today” according to engineering educators David E. Goldberg and Mark Somerville.[20] Based on a cursory review of courses required in U.S. engineering schools they concluded “that a very small proportion include the word “design” and even fewer address creativity in a deliberate way.” Considering just the design courses, they observed that many “include very little discussion of creativity and the thought processes that underlie it” which they consider remarkable “given the importance of this mode of thinking to the fundamental purpose of engineering.”

**Summary: Creativity/Innovation in CE Education Programs**

We’ve been considering this question: Aren't creativity/innovation already in CE education programs? Based on my experience, the recent mini-survey, and the thoughts of various educators, I believe that creativity/innovation receive minimal to moderate emphasis in most undergraduate CE education programs and when they do it is mostly in the last year.

## Aren't Creativity/Innovation Already in the Engineer Intern Experience?

A thought in recognition of the already-full curricula might be that creativity/innovation don't need significant attention in CE education programs because that KSA set is addressed during the Engineer Intern process. That is and broadly speaking, formal education stresses analysis and, while it may include some creativity/innovation content, creativity/innovation are learned as part of design during the pre-licensure experience.

My career includes three decades in full-time private and public practice. Informed by that experience, I know that many Engineer Interns will receive at least modest design assignments. However, those tasks will tend to be carried out in a conventional manner using algorithmic approaches largely devoid of creativity/innovation expectations. Furthermore, if the intern did not learn creativity/innovation fundamentals as part of his or her formal education, the probability of acquiring those basics prior to and even beyond licensure is very small.

Finally, consider my experience over the past half-dozen years, during which I developed a strong interest in creativity/innovation and have studied, written, and spoken about them. I have encountered mostly lack of interest and some push-back from engineering organization leaders and managers.

For example, in response to a client's request to suggest topics I could present or facilitate at their annual senior manager's meeting, my ideas included a session on using neuroscience basics to work smarter which would include ways to be more effective, efficient, and creative/innovative. The response of the five top executives I was working with was unanimous — no interest! One of them explained their position by saying something like this: "We are in the trenches 10 hours each day and don't have time for philosophical, academic, and theoretical stuff like that." Ironically, the goal of my proposed creativity/innovation session was to shorten their trench-time or even get them out of the trenches and position them to more effectively create, innovate, and lead.

My conclusion: While there is considerable talk about creativity/innovation in the world of CE practice, there is very little commitment to it. Therefore, CE graduates not already aware of and prepared to be creative/innovative are very unlikely to do so as a result of their engineering internship.

## Observations based on the Previous Parts of this Paper

I conclude that the CEBOK gives minimal attention to creativity/innovation, that creativity/innovation are not widely taught and learned in CE bachelor programs, and that creativity/innovation fundamentals are not acquired during pre-licensure experience. Unless further investigation convinces me otherwise, we are not preparing U.S. civil engineers to be creative/innovative. Yes, some will because of personal characteristics and fortuitous circumstances. However, we could and should do much better for the sake of individual engineers and for the benefit of society. A rising tide would lift all boats.

From here on, this paper assumes the reader, while perhaps not convinced of the previous conclusion, is open to considering ideas for strengthening creativity/innovation in the CEBOK and, partly as a result, in CE educational programs (and during the Engineer Intern experience).

## Options for Including Creativity/Innovation in the CEBOK

Consider two ways to explicitly include creativity/innovation in a third edition of the CEBOK, or as an amendment to the second edition. The options are adding an outcome and introducing a strong creativity/innovation theme. One or both of these approaches could be used.

## A New Outcome

A third edition might result in outcome deletions or additions similar to when the first CEBOK, published in 2004, transitioned to the second edition,[1] published four years later, with additional outcomes. The rubric form of a creativity/innovation outcome could be as follows presented in the Bloom's Taxonomy format (Appendix I of the CEBOK2 report[1]):

1. Knowledge -- Define creativity/innovation. (B)

2. Comprehension -- Describe how being creative/innovative differs from the traditional engineering problem-solving process. (B)

3. Application -- Use knowledge of creativity/innovation principles and methods to conceptualize potential solutions to a well-defined problem and conceptualize potential solutions. (B)

4. Analysis – Analyze an actual problem using creativity/innovation principles and methods. (M/30)

5. Synthesis – Develop a creative/innovative solution to an actual problem. (E)

6. Evaluation – Evaluate the creative/innovative aspects of the solution to an actual problem.

## A Creativity/Innovation Theme

Recall the conclusion in the section of this paper titled "Aren't Creativity/Innovation Already in the CEBOK?" that the report gives minimal attention to creativity/innovation. The next edition of the CEBOK, or amendments to the second edition, could include many meaningful uses of "creativity" and "innovation" and variations on them (e.g. create, innovate, creative, innovative). Such words could appear in more than one rubric (as “create” does now in Outcome 15) where they would have the most influence and the intent would be to encourage more creative/innovative thinking in defining issues, problems, and opportunities and in resolving them.

For example, consider Outcome 9, Design.  Level 5, Synthesis, now reads "***Design*** a system or process to meet desired needs within such realistic constraints as economic, environmental, social, political, ethical, health and safety, constructability, and sustainability.” Creativity/innovation could be encouraged by adding this text “…and for some ***apply*** creative/innovative principles and tools.”

Outcome 9 for Level 6, the E level, now states "***Evaluate*** the design of a complex system, component, or process and ***assess*** compliance with customary standards of practice, user's and project's needs, and relevant constraints." It could be expanded with this creativity/innovation statement: "…and for some, ***assess*** the extent to which creative/innovative principles and methods were used."

Outcome 10, Sustainability, at Level 3, the B level, states "***Apply*** the principles of sustainability to the design of traditional and emergent systems." It might be expanded with: "…and for the emergent ones ***illustrate*** how creative/innovative principles and methods were used."

## Comparison of the New Outcome and Creativity/Innovation Theme Ideas

The new outcome approach would initially receive more attention because it is a new outcome. Some of that attention would be positive given the apparent interest of some faculty to take a more systematic approach to creativity/innovation in CE programs. In contrast, a new outcome would elicit some negative reactions partly because of the tendency of some faculty to connect outcomes with courses.

While creativity/innovation can be viewed as a knowledge-skill-attitude set, like most outcomes, it can also be seen as a way of thinking and, therefore, applicable across all or most outcomes. Thus a new outcome could serve two functions.

The theme approach, while it might not attract as much initial attention as the new outcome option, may enjoy more sustained attention because references to various aspects of creativity/innovation would appear in many outcomes and at the B, M/30, and E fulfillment levels. Those repeated appearances could challenge faculty to integrate creativity/innovation into the curricular and co- and extra-curricular elements of their CE programs.

Having noted some of the pros and cons of the two ideas, recognize the possibility of using both of them thus generating a third way to include creativity/innovation in the CE BOK. In keeping with this paper's purpose ("stimulate thinking about creativity and innovation as ASCE moves toward the next CEBOK, or amendments to the existing version"), I am neither compelled nor prepared to recommend how to integrate creativity/innovation into the CEBOK. I recommend that means such as a new outcome, a theme, and/or both be considered along with the inevitable other ideas that will be generated.

## Fitting Creativity/Innovation into an Already-Full Curriculum: A Strategy and Some Tactics

Assume, for discussion purposes, that creativity/innovation became an integral part of the CEBOK. That would motivate some faculty members to consider ways to integrate that KSA set into their programs. Even without that incentive, some faculty have and will continue to incorporate creativity/innovation on its merits as suggested, in part, by the mini-survey, published articles, and my observations.

How can we fit creativity and innovation into an already full academic program, that is, its curricular, co-curricular, and extra-curricular aspects? What overall strategy could we adopt and what tactics can we use to implement the strategy and to "stuff" even more value into the undergraduate experience?

## Teaching and Learning Creativity/Innovation: A Strategy

The strategy should be a unifying structure that identifies essential content and its distribution over undergraduate and graduate portions of the program. While the strategy should focus on the curriculum it should also influence co- and extra-curricular elements of CE programs. Finally, the strategy should strike a balance between stimulating creative/innovative thinking about how to enable students to be more creative/innovative while not be overly prescriptive.

In keeping with the preceding criteria, a suggested strategy follows. It consists of four major elements – Need, Neuroscience, Tools, and Applications -- as illustrated in Figure 1. Consider each of the elements.

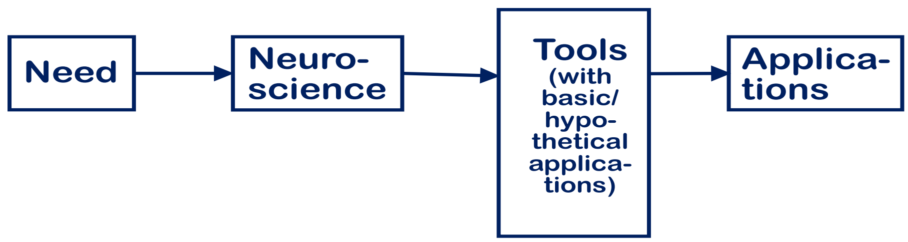


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**Figure 1.** A suggested strategy for integrating creativity/innovation into an academic program consists of four elements.

**1. Need -- Explain growing need for creativity/innovation.** Elaborate on the need to be more creative/innovative, as noted in this paper's Introduction. Explain the Grand Challenges for Engineering; the coming of the Conceptual Age, Opportunity Age, and Wicked Problems Age; practicing better stewardship with aspiring engineers and their intellectual gifts; the satisfaction of serving the public by doing what has not been done; and attracting and retaining the best and brightest young people in the profession.

**2. Neuroscience – Present selected neuroscience discoveries and explain their relevance to creative/innovative thinking.** An understanding of brain basics will help students study and work smarter and be more creative-innovative. As noted by consultant Robert Cooper[21], "It's an amazing instrument, your brain, but it's up to you to see that it plays the tune you want." Playing that tune requires a basic understanding of how the instrument works.

"Ninety-five percent of what we know about the capabilities of the human brain has been learned in the last twenty years," according to author Michael J. Gelb.[22] Richard Restak,[23] M.D., wrote "We have learned more about the brain in the past decade than we did in the previous two hundred years." "There is perhaps no greater untapped resource in the universe than the human brain," as noted by clinical neuropsychologist Paul D. Nussbaum,[24] "the human brain is no longer the domain of academia and medicine."

Students could be introduced to the human brain's features and functions and the distinction between the brain and the mind. More specifically, and as illustrated in Figure 2, help them learn about the brain's symmetrical hemispheres and related lateralization, the critical asymmetrical exception, and formal education's focus on the left side. Also inform them about neuroplasticity and its potential for maintaining and improving life-long cognitive functions, our conscious and subconscious minds, the power of habits and our ability to replace them, the wastefulness of multitasking, our built-in negativity bias, the vagaries of handedness, the value of understanding gender differences, and how we know what we know about the human brain.[25]

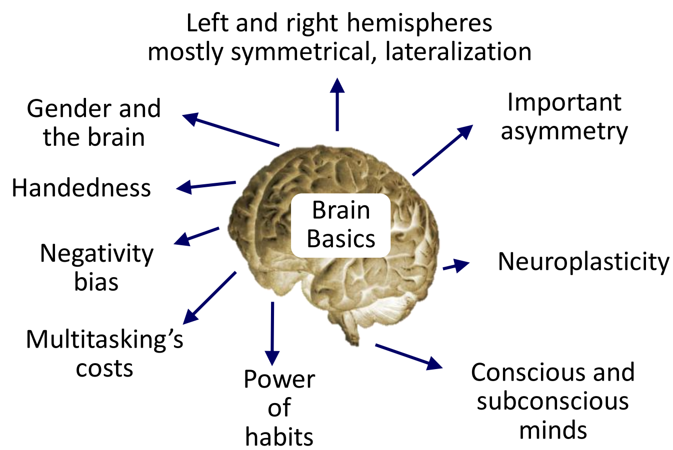


**Figure 2.** Many features of the human brain are relevant to working smarter and enhancing creativity and innovation.

**3. Tools – Describe and illustrate use of thinking/collaboration methods.** The quality of decisions at any point in an endeavor, whether arrived at individually or as a team, is likely to be better when we have more ideas -- more options. The value of more ideas is widely applicable in engineering. It enhances our ability to address challenges we face with structures, facilities, systems, products, and processes as well as in non-technical areas such as human resources, accounting, finance, marketing, and management. This early-on-more-ideas-is-better concept applies whether we are striving to **define** an issue, problem, or opportunity or we are endeavoring to **resolve** one.

We want the thinking effort to be rich and varied. In the world of idea generation, more is usually better! Scientist Linus Pauling said "the best way to have a good idea is to have lots of ideas." American writer John Steinbeck put it this way: "Ideas are like rabbits. You get a couple, and learn how to handle them, and pretty soon you have a dozen."

Creative/innovative ideas lie within most of us. However, we need mechanisms to release them. Fortunately, many tools are available to students, working alone or in collaboration with others, to engage both cranial hemispheres, employ their conscious and subconscious minds, and make use of other brain basics.

Some of the methods can be explained and then applied somewhat methodically, that is, in a step-by-step manner. Examples are Brainstorming, Fishbone Diagramming, Mind Mapping, SWOT (Strengths, Weaknesses, Opportunities, Threats), and Process Diagramming. Other tools, rather than being described as a process, are more ways of thinking about an issue, problem, or opportunity. They are approaches taken or attitudes exhibited when faced with a complex situation. Examples are Borrowing Brilliance, Medici Effect, Take a Break, What If?, Freehand Drawing, and Supportive Culture and Physical Environment.[25,26]

As part of the process of introducing thinking/collaboration methods to students, mostly basic/hypothetical applications could be used. These initial applications would set the stage for the fourth and final element of the strategy.

**4. Applications – Apply brain basics and creativity/innovation tools to technical and nontechnical challenges.** Building on preceding elements (Need, Neuroscience, Tools), students could be challenged and encouraged to proactively and systematically seek creative/innovative ways to address issues, solve problems, and pursue opportunities within their courses, their co- and extra-curricular activities, and in their community and personal lives. Creative/innovative thinking, at both the individual and team level, could become part of the academic life and culture. And, of course, that mindset could be carried by students into their subsequent professional practice and beyond.

The preceding four elements of the strategy for creativity/innovation teaching and learning could be embedded in undergraduate and graduate curricula as shown in Figure

3. Rather than develop a separate course, which I view as undesirable except when it is the only way to experiment, the creativity/innovation elements would occur throughout the undergraduate-graduate curriculum as small parts (modules) of many courses and as small parts of co- and extra-curricular activities. This “creativity/innovation across the curriculum” approach would be similar in spirit and execution to the “writing across the curriculum” movement.

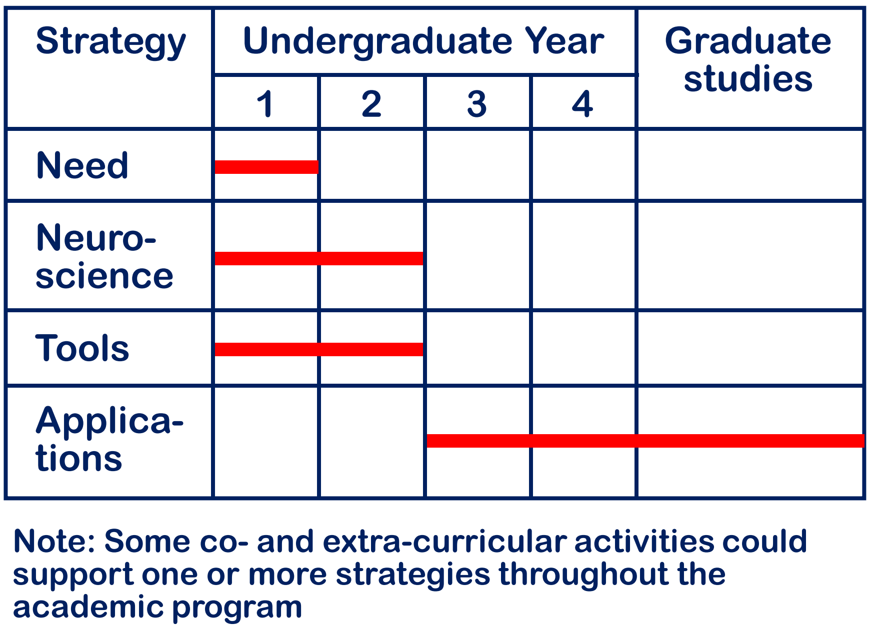


**Figure 3.** The strategy for teaching and learning creativity/innovation could be embedded in undergraduate and graduate curricula.

As suggested by Figure 3, the strategy includes explaining the need for creativity/innovation to first-year students, providing them with some neuroscience basics, and introducing them to a subset of tools and basic, mostly hypothetical applications. This introduction to creativity/innovation could occur primarily within and as a small part of an exploring engineering, introduction to engineering, or similar preferably first-semester course. Of course, the Need, Neuroscience, and Tools elements of the strategy could be mentioned in other first-year courses and in some co- and extra-curricular activities. Begin to develop a culture that includes the idea that “to engineer is to create.”

Second-year students would acquire more brain basics and learn about more methods and their basic and hypothetical applications. This would occur as coordinated small parts of several courses and in selected co- and extra-curricular activities.

Third and fourth year and graduate students would focus on applying tools to resolving higher-level and mostly real issues, problems, and opportunities. Again, these applications would appear each semester or quarter in multiple courses and as parts of co- and extra-curricular activities.

Students who enter practice immediately after earning the bachelor's degree would, because of the four-year exposure to creativity/innovation, carry that mind set and the underlying principles and tools with them. Students who go directly into master's or PhD programs will be very well equipped to think creatively/innovatively in those endeavors.

## Teaching and Learning Creativity/Innovation: Some Tactics

Let's consider 20 preliminary curricular, co-curricular, and extra-curricular tactics or ideas. The extra-curricular options are especially attractive when an engineering college is part of a diverse university environment. My purpose is to stimulate creative/innovative thinking about how creativity/innovation can be integrated into undergraduate CE and similar programs. Most of the listed tactics are drawn from my experience and research and reflect what I have presented or published[3,26,27,28,29]. I am indebted to Professor Richard H. McCuen, Ben Dyer Chair in Civil Engineering at the University of Maryland, for encouraging the presentation of this list of ideas and for providing some of the content.

1. Learn from others and share what you are learning with them. Interact with colleagues and others by drawing on your network, searching the internet, and attending conferences.

2. Arrange for in-house faculty development activities focusing on what we have recently learned about the amazing human brain and how that knowledge is practical and immediately applicable in enabling student and practicing engineers to be even more creative/innovative.

3. Leverage your first-year Exploring Engineering, Introduction to Engineering, or similar courses during which student teams take on some well-defined design problems. Briefly describe some creativity/innovation tools and ask each team to use one or more of those collaboration methods to more fully utilize their collective minds.

4. Continue to introduce the tools in the remaining years of the undergraduate program building on the first-year introduction.

5. Include the topic of creativity/innovation in an honors course where students are asked to identify a challenging issue, problem, or opportunity; examine alternatives; provide a solution; and put it into operation.

6. Include the creativity/innovation topic in National Science Foundation Research Experience for Undergraduates (NSF-REU) and similar externally or internally sponsored undergraduate research experiences.

7. Develop and offer a one to three-credit course devoted to creativity and innovation. This approach is, in my view, much less desirable than the across-the-curriculum model common to most of the preceding and following suggestions. The principal value of creativity/innovation fundamentals is that they are applicable to essentially all courses. However, a creativity-innovation course can be an effective way to insert creativity/innovation into a curriculum, at least on an experimental basis, and then observe student and faculty responses.

8. Apply Bloom's Taxonomy when establishing the level of cognitive achievement for various parts of courses with emphasis on setting high levels for design-related parts of courses. High expectations are likely to stimulate students to be even more creative/innovative.

9. Recognize that the vast majority of creative/innovative tools share this practical common feature: They are easy to understand, take little time to apply, and they work. Accordingly, they can be introduced and used with little effort in most courses.

10. Share or point to creativity/innovation stories for their motivational and instructional values. For example, review the origin of Velcro, Guttenberg's printing press, automobile assembly line, bar code, integrated circuit, Panama Canal, vulcanization, masking tape, precision agriculture, and bionic prostheses.

11. Counsel graduate students who are struggling with finding a research topic or making progress on one. Urge them to independently study creativity/innovation as a discipline or way of thinking.

12. Arrange for inventors and entrepreneurs to speak in classes. Suggest that student groups, such as student chapters of professional societies, invite inventors and entrepreneurs to speak at their meetings.

13. Start an inventor or entrepreneur-in-residence program.

14. Interview artists and other "creative" types. Ask about the sources of their creativity/innovation. Compare and contrast the mind sets and processes used by artists with those employed by engineers. Ask artists what they view as the characteristics of creative/innovative colleagues and query them about recognizing and overcoming obstacles to creativity/innovation.

15. Study the origins of an admired engineered structure, facility, system, product, process, or service. Engineering students and faculty can learn much by studying how other engineers achieved creative/innovative results.

16. Participate in student creativity/innovation competitions.

17. Raise student awareness of creativity/innovation, or lack thereof, during "co-op," internships, summer employment, and part-time jobs. Encourage students, while participating in these activities, to look for creative/innovative developments and determine the extent to which they are valued and encouraged. How important is organizational culture to creativity/innovation and, more personally, to a particular student?

18. Urge students to be aware of the creativity/innovation statements often made by leaders of business, government, academia, and other organizations and are commonly reported in public media. Suggest critically checking these pronouncements against actual policies, processes, and results.

19. Conduct controlled experiments. For example, form a hypothesis such as engineering students will perform better academically if they learn and apply creativity/innovation tools or engineering students will be more creative/ innovative if they participate in visual arts. Conduct the experiment (e.g., using parallel sections of the same course), analyze the data, draw conclusions, and share the results.

20. Assess the long-term results of explicitly including creativity/innovation in CE programs by determining the impact, if any, on:

- Student and faculty motivation and morale
- Student recruitment and retention
- Breadth and depth of faculty and student research projects and the creativity/innovation evident in the results
- Alumni success and significance
- Strengthened and/or expanded relationships with industry
- Funding, equipment, and other resources received from external sources
- Image and reputation of the department, college, and/or institution

Most of the preceding curricular, co-curricular, and extra-curricular ideas and actions are not so much add-ons as they are variations on what faculty and students are doing now, in and outside of the classroom, although not necessarily with the creativity/innovation topic. In this case, the focus is on creativity/innovation. Some of the suggested tactics can be part of advising and mentoring including urging students to take full advantage of campus activities, many of which offer creativity/innovation opportunities.

## Faculty Development

Implementing the preceding strategy and tactics, or something like them, would require a major effort in most undergraduate CE programs. Some faculty would push back because of the perceived major change or the "impossibility" of "stuffing" more into an already loaded undergraduate experience.

Even receptive faculty would be challenged because topics such as brain basics and creativity/innovation tools are likely to be new to them. However, and this is a key point, many of us are teachers because, at heart, we are perpetual students and long-ago discovered that a great teacher is first a great student. We entered teaching because we wanted a profession that would enable us to continue to be students. We understand the comment by the French essayist Joseph Joubert that "to teach is to learn twice." Many of us would, as I have, become intrigued by how neuroscience fundamentals and related thinking/collaboration tools might impact our students, now and in their careers.

That uplifting thinking could cause the teacher in us to go further, which I have not done yet in this paper and will now only touch on. We might ask if knowing brain basics might make us be even better teachers. Author and biology professor James E. Zull thinks so as he tries to explain in his book *The Art of Changing the Brain*[30]. He chose that title because he defines teaching and learning as the teacher and the student working together to physically change the student's brain. Therefore, if we are going to change something we need to understand the something. Zull refers to the "biology of learning" as a way of encouraging teachers to study the human brain. Educator Mariale M. Hardiman takes a similar tact in her book *Connecting Brain Research with Effective Teaching: The Brain-Targeted Teaching Model*[31]. She urges educators to "become better consumers of the mountains of research that have emerged since the 1990s."

The point of this section is that most faculty members who become intrigued by a creativity/innovation initiative would need and welcome some help from their department, college, institution, and/or professional societies. They are unlikely to have the necessary neuroscience background and thinking/collaboration tools knowledge and skill. Faculty development programs will be necessary.

**Summary of Key Ideas**

This paper seeks to stimulate thinking about creativity/innovation as ASCE moves toward the next CEBOK or amendments to the existing version. That objective is accomplished by:

- Stating that **creativity/innovation will be increasingly important for U.S. engineers** because of forces such as resolving the environmental, social, and economic challenges facing society; maintaining U.S. global leadership and enhancing national security; stimulating organizational vitality; practicing better stewardship with aspiring engineers and their intellectual gifts; attracting even more of the best and brightest young people to the profession and retaining them; and experiencing the satisfaction of doing what has not been done.

- Concluding that the CEBOK gives minimal attention to creativity/innovation, that creativity/innovation are not widely taught and learned in CE bachelor programs, and that creativity/innovation fundamentals are not acquired during pre-licensure experience. **We could do much more to prepare U.S. civil engineers to be creative/innovative** for their sake and for the benefit of society. A rising tide raises all boats.

- **Recommending that creativity/innovation be integrated into the CEBOK** by means such as a new outcome, a theme, and/or both and the inevitable other ideas that will be generated if this integration topic is discussed.

- **Suggesting a strategy for fitting creativity and innovation into the curricular, co-curricular, and extra-curricular aspects of already full CE programs.** It consists of four major elements – Need, Neuroscience, Tools, and Applications -- and could be implemented using tactics such as the many listed near the end of this paper. Faculty development programs will be required.

I hope that ASCE's Raise the Bar leaders will find this paper's exploration of creativity/innovation useful as they embark on the next update of the CEBOK.

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## Appendix A: Search for Creativity/Innovation or Similar Terms in the Explanations of Outcomes Appendix of the CEBOK2 Report

A search of "Explanations of Outcomes" (Appendix J in the CEBOK report[1]) finds a few references to "creativity" and/or "innovation" or variations on them. The search is described as follows:

- Outcome 8: Problem Recognition and Solving – "Creative" is used in the Overview section where it is used to refer to alternative solutions as "both routine and **creative.**"

- Outcome 9: Design -- "Innovative" appears in the Overview section as in "The design process is open-ended and involves a number of likely correct solutions, including **innovative** approaches." "Creative" is used in the discussion of the level of cognitive development to be "fulfilled through the bachelor's degree," also called B, as in "Fostering **creative** knowledge in students prepares them to handle a future of increasing complexity that relies on a multidisciplinary approach to problems." This is the strongest use of creativity/innovation-type words in the Explanation of Outcomes.

- Outcome 15: Technical Specialization -- As already noted, in the rubric discussion, "create" appears in the M/30 level of cognitive achievement definition. "Creation" and "create" appear in the explanation of M/30.

- Outcome 16: Communication -- "Created" appears in the Overview as part of the definition of virtual communication and "create" is used in the explanation of the B level where it refers to preparing graphics.

- Outcome 20: Leadership – "Creativity" is used in the Overview section as in "inspiring **creativity**" is one element of leadership.

Refer to the section of this paper titled **"**Aren't Creativity/Innovation Already in the CEBOK?" for a summary of the preceding and its significance.

## Appendix B: Instrument Used for Mini-Survey

The following request was sent once (no reminders) by the author in early December 2014, as a personal email, to 32 faculty who he knew and who have first-hand knowledge of CE and similar programs:

> I'm preparing a paper titled "Creativity and Innovation as Part of the Civil Engineering BOK" for presentation at the 2015 ASEE conference and would like to learn more about the coverage of creativity-innovation in civil and related engineering programs. Therefore, I am conducting a "mini-survey" by personally contacting about 25 faculty, like you, that I know. My hope is that you and others will answer four questions. Your responses will give me a preliminary understanding of how creativity-innovation is being integrated into curricula and co- and extra-curricular activities.
>
> Survey results are confidential in that I will not use your name or that of your institution. I will provide you with a copy of the paper for your review and possible use.

**The 4 questions are:**

1) Does your department's undergraduate curriculum include a required course or a portion of a course that explicitly strives to help students be more creative/innovative?

____ Yes, an entire course

____ Yes, a major portion of a course

____ Yes, a minor portion of a course

____ No

Optional comment:

2) Regardless of the answer to Question 1, are creativity/innovation explicitly taught and learned across most of your engineering curriculum, that is, do a majority of the faculty who teach engineering courses specifically and systematically strive to help their students be more creative and innovative?

____ Yes

____ No

Optional comment:

3) Regardless of the answer to Question 2, do essentially all students participate in co-curricular or extra-curricular activities that help them be more creative-innovative?

____ Yes

____ No

Optional comment:

4) If you could change one thing about your undergraduate curriculum's approach to creativity and innovation, it would be:

Optional comment:

If more convenient, we can have short conversation by phone.

Thank you for considering my request.

## Appendix C: Results of Mini-Survey

Eighteen faculty completed the survey instrument shown in Appendix B as of early January 2015. Results of the three multiple-choice questions are presented below. Also included are the responses to the last query and some of the optional comments for all four questions which were selected to illustrate a wide range of views.

**The results are:**

1) Does your department's undergraduate curriculum include a required course or a portion of a course that explicitly strives to help students be more creative/innovative? (A “Y” indicates that the respondent was known to be referring to a senior project or similar senior course)

Yes, an entire course : XXYY

Yes, a major portion of a course : YYY

Yes, a minor portion of a course : XXXXX

No : XXXXXX

Optional comment:

- While our design courses “speak” to the concept of innovation in design, the primary focus is on established design procedures, codes, and specifications. There is not a push for “innovation” in the design process.
- The University has a major thrust towards critical thinking across all degree programs. Therefore, all engineering courses include modules and approaches that actively promote critical thinking and innovation.

2) Regardless of the answer to Question 1, are creativity/innovation explicitly taught and learned across most of your engineering curriculum, that is, do a majority of the faculty who teach engineering courses specifically and systematically strive to help their students be more creative and innovative?

Yes : XXXXXXXX

No : XXXXXXXXXX

Optional comment:

- These are characteristics of a good civil engineer [that] we aim to instill this in our graduates.

- I believe that our faculty do [strive to help their students be more creative and innovative], however, students that are struggling and/or just trying to grasp material and pass the course determine the amount creativity can be incorporated and essentially dictate the pace of the course.
- I have personally pushed hard to include aspects [of end-of-term projects] that require unconventional learning styles and have had good response for students exploring aspects that encourage creativity in their presentation of materials.

3) Regardless of the answer to Question 2, do essentially all students participate in co-curricular or extra-curricular activities that help them be more creative-innovative?

Yes : XXXXXXXX

No : XXXXXXXXXX

Optional comment:

- Our primary opportunities for co- and/or extra-curricular activities are typical: study abroad/experiential learning; competitions (steel bridge, concrete canoe, etc.); service learning, etc. The students participating in these types of activities represent less than half of the total UG student population in our program.
- The emphasis on co-curricular activity characterizes [our institution]… and the participation rate is high.
- These experiences absolutely help the students be more creative-innovative.

4) If you could change one thing about your undergraduate curriculum's approach to creativity and innovation, it would be:

Optional comment:

- We really need to address this issue…needs to start at the freshman intro to engineering level course.
- More extensive involvement of all undergraduate students in research.
- Creativity and innovation are intensive activities…are difficult to implement unless the faculty member takes it upon himself or herself.
- Provide more training opportunities for faculty so that they can better guide students in this area.
- The main change that might help is to place more emphasis on design and discovery of solutions, which is a tough challenge given the management requirements of the curriculum.

- The freedom to fail, the freedom to experiment with designs which may or may not work.
- Recent discussions on related topics identified the need to better develop and integrate skill-centric knowledge with technical domain knowledge through problem-based learning activities and mentorship.
- I would have fewer students per faculty member so we had the ability to practice these teaching methods.
- I would include opportunity for more open-ended problems and promote groups of students working independently in teams to come up with creative solutions for real problems. This of course would require close supervision and guidance by faculty.
- Creativity and innovation insertion has to become part of faculty evaluation/incentive system.
- An increase in emphasis on creativity. This could be aided by doing this in high school.
- Add a course or module on design concepts espoused by the D-School at Stanford.
- Have more concerted effort placed on systematic integration of curricular content related to innovation to support the discrete exercises that students are exposed to throughout the curriculum.