

Innovative Confidence: what engineering educators need to understand and do to graduate more effective innovators and intrapreneurs

Abstract

Many innovation leaders recommend attributes, mindsets and behaviors that require high levels of confidence and self-efficacy. As such, innovation rests upon the individual's sense of self and his/her confidence to perform various activities that are essential to innovation. These include creativity, ethnographic research, challenging the status quo, teamwork, making presentations and accepting constructive criticism, most of which are anxiety-producing for students, especially early in their engineering education.

However, there is little engineering education research that focuses on the ways in which engineering faculty members might simultaneously develop the competence and the confidence of their students, especially as it relates to these activities, or how they can avoid creating the fear and subsequent insecurity that diminishes student performance of them.

This paper first discusses previous research and relevant literature linking confidence and self-efficacy to innovation. It then examines the central activities of innovation and the ways in which student learning activities and faculty members' interactions with students may negatively impact student confidence, and, indirectly, their competence. A pedagogical strategy of "scaffolding" is proposed whereby confidence and competence repeatedly build upon each other, building upward in steps of increasing size. Recommendations are provided for ways faculty members can develop a milieu of innovation and apply scaffolding to key tasks of innovation, ethnographic research, creativity/ideation, design reviews and teamwork.

Background Research: Why confidence is important to Innovation and Intrapreneurship

Over 100 corporate innovation leaders were asked the question, "What behaviors and competencies do you want in your new engineers that would make them more effective innovators and intrapreneurs in your company?" Many of them recommended attributes and mindsets that depend on one's self-confidence in general or self-efficacy regarding specific innovation activities. (Hanifin, 2013) These leaders held titles that ranged from CEO, Corporate Vice President for Worldwide Product Development, and VP Engineering and Architecture to

Master Inventor, Director - Advanced Product Creation, Director - Technology and Development, Colonel, USAF, and even “Chief Skunk” (at the iconic Skunk Works at Lockheed Martin).

Leaders from all but one of the ten companies participating in this study of innovation in corporations recommended that innovative engineering graduates have high levels of confidence and/or attributes and behaviors that depend directly on such confidence. It is not enough that an innovative engineer be *competent*. He/she must also have the *confidence* needed to behave and act in the following ways:

Confidence-dependent Behavior/Attribute	Mentioned by innovation leaders at:
1. Question the status quo enough to consider disruptive solutions	DuPont, IBM, Lockheed Martin, Pankow (construction)
2. Take risks and learn from failures	IBM, Lockheed Martin
3. Low fear of failure	BASF, Campbell Soup
4. Be a self-starting seeker of opportunities	Air Force, Lockheed Martin, Pankow, IBM
5. Have the pride and motivation to make a big difference	BASF, IMDS (medical devices), Lockheed Martin, Pankow
6. Have the integrity to tell the truth, even when its bad news	Ford
7. Live with and function well with ambiguity	Ford

All of these capabilities were suggested as important to being an innovative engineer and an intrapreneur in corporations, and all depend to a significant degree on ones’ self-confidence. In fact, without self-confidence, it is difficult for a person to do any of these things.

While there are all of these positive impacts of a high level of self-confidence, it is also possible to become over-confident, or to have a false confidence or bravado that is not based on true competence or mastery of one’s profession. If self-confidence becomes over-confidence, the engineer may lose the ability to accept criticism that improves the design or product. This behavior may occur in design team meetings when engineers, in their zeal to promote and *sell* their innovation, blind themselves to valid concerns or valuable modifications regarding the concept or product that could make it even better. For recent engineering graduates, who are trying to find or establish their place in the organization, such reactions to critiques of their design may be derived from defensiveness. This is especially so if they believe that the design critique reflects any lack of confidence (real or perceived) by more senior engineers or managers.

All of this points to a key linkage between confidence and mastery of the capabilities (competence) that are central to the engineering profession. If one’s confidence is based on true mastery, then the engineer will view questions and critiques regarding his/her design as valuable contributions towards excellence in the outcome. It becomes a contribution toward the success of the innovation, rather than a personal challenge to one’s capability. It is this balance of confidence and openness (to examination of the person’s concepts or designs) that is ideal for the most effective innovators.

These forces of competence and confidence reach a crescendo in the prototypical engineering activity of the *design review*, a common practice in both industry and academe. The design review is the locus of critical review of an engineer's creative and analytical contributions, and, as such, is a cauldron of emotion fueled by . . .

- pride in one's work,
- emotional responses to assessment of that work by peers and superiors,
- anxiety regarding external motivators of grades, pay and future career opportunities,
- anxiety regarding criticism of one's mastery,
- acceptance or rejection of critical comments that may improve the project results and team success.

The net result of the interacting emotions may be anything from a meltdown of the engineer's confidence (and concomitant drop in innovation-related competencies) to a team experience that improves the product, learns about the product/customer domain and builds team esprit de corps (and builds innovation-related competencies of individuals). These outcomes depend on many things including the dynamics of the design review and tone and content of feedback by participants who hold higher levels of authority, such as managers in industry or faculty members in academia.

A healthy balance of ever-improving competence and justifiable confidence of the engineers can be developed by engineering educators as they engage students in the review of their design projects, and maintained by effective engineering leaders in industry as they run the design reviews of their companies. However, if engineering professors provide only severe criticism of students' design projects, they risk destruction of the students' self-confidence. If they only encourage without feedback on a concepts shortcomings, then a false sense of self-confidence without mastery may result. Conversely, if professors couch their comments in the context of aiding the student in achieving mastery of engineering, the student's motive may change from seeking praise and high grades (extrinsic) to seeking mastery (intrinsic) . . . a far more effective motivator. (*Drive*, Daniel Pink)²¹

Derrick Kuzak, Group Vice President for Global Product Development at Ford Motor Company, understood the need for a balance of encouragement and criticism that must be applied during Ford's design reviews. He described the importance of design reviews and their balance of mastery and confidence as follows:

The design review process is one of the most important operating mechanisms that we have in the engineering community. Design reviews are led by technical specialists. One of their jobs, in *fact their most important job, is to lead design reviews and make it a constructive learning experience for all of the engineers. These meetings are hard-nosed design reviews . . .*, often run over digital systems with people from around the world. (Kuzak, 2012)

Leaders at Lockheed Martin and Pankow also recognized that need to balance confidence with openness and respect for input from others. The leaders at the Skunk Works © said that young

engineers need to “know when you’re in over your head (and who to go to for help).” At Pankow there was a recognition that over confidence could inhibit effective teamwork; “The hard chargers in the field often rise to the top, but then (when they return to the office to lead project teams) are too harsh with people under them. “ (Hanifin, 2013)

The Influence of Confidence and Self-Efficacy on Innovation

High levels of confidence and self-efficacy enable individuals to have the courage to attempt harder tasks and to attempt riskier and more innovative solutions. Confidence is a broad sense of self, while self-efficacy is related to specific tasks. Self-confidence is one’s broad belief in their ability to produce results, accomplish goals or perform tasks well. The level of performance of specific tasks by anyone, including engineers, depends not only on their task-related capabilities (competence), but upon their motivation and confidence to complete the task (self-efficacy), and, in a negative way, their anxiety/insecurity level. Noted psychologist Albert Bandura describes the impact of self-efficacy on an individual as follows:

People with high assurance in their capabilities approach difficult tasks as challenges to be mastered rather than as threats to be avoided. Such an efficacious outlook fosters intrinsic interest and deep engrossment in activities. They set themselves challenging goals and maintain strong commitment to them. They heighten and sustain their efforts in the face of failure. They quickly recover their sense of efficacy after failures or setbacks. They attribute failure to insufficient effort or deficient knowledge and skills which are acquirable. They approach threatening situations with assurance that they can exercise control over them.
(Bandura, Self-Efficacy, 1994)

These behaviors of the confident person with high self-efficacy are precisely the same behaviors that innovation leaders desire in their engineering innovators. As such, it would be valuable for engineering educators to understand the impact of self-efficacy and confidence on the learning and performance of engineering functions, especially those central to innovation.

Bandura defines *perceived self-efficacy* as “people’s beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives.” (Bandura, Self-Efficacy, 1994). Carberry and Lee, in their paper “Measuring Engineering Design Self-Efficacy” narrow this focus on the activities related to design, the central function of engineering, as follows, “Self-efficacy refers to an individuals’ judgment of their capability to organize and execute courses of action for a given task (Bandura, 1986; 1997). According to self-efficacy theory, the level of self-efficacy for a given task is influenced by other task-specific self-concepts including motivation, outcome expectancy, and anxiety or self-doubt toward the task (Pintrich and Schunk, 2002).” (Carberry A. H.-S., 2010)

The implication of this research for engineering educators is that as students develop their competence for an engineering task, they are better able to perform that task . . . leading to higher confidence/self-efficacy . . . leading to willingness to take on more complex, challenging tasks . . . leading to intrinsic motivation and learning of competence . . . and onward in a spiral upward of parallel increases in confidence and competence, leading to engineering mastery (Figure 1).

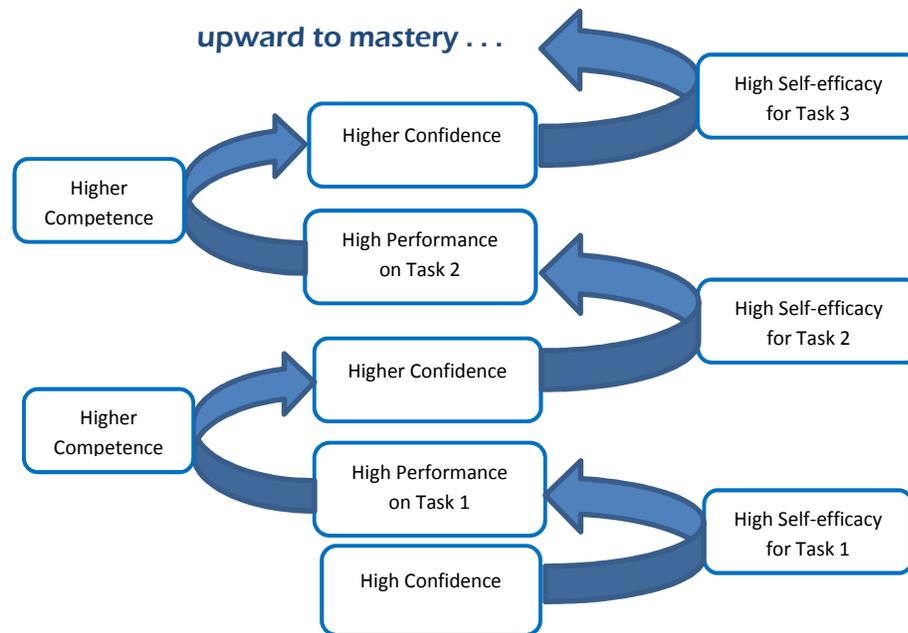


Figure 1 - The Upward Spiral of Higher Confidence and Competence

Schunk describes this upward spiral in terms of the student's academic development:

Initial self-efficacy varies as a function of aptitude (e.g., abilities and attitudes) and prior experience. Such personal factors as goal setting and information processing, along with situational factors (e.g., rewards and teacher feedback), affect students while they are working. From these factors students derive cues signaling how well they are learning, which they use to assess efficacy for further learning. Motivation is enhanced when students perceive they are making progress in learning. In turn, as students work on tasks and become more skillful, they maintain a sense of self-efficacy for performing well. (Schunk, 1991)

Of course, high self-efficacy does not, by itself, guarantee success in completion of the task. One must also have the competency in the skills requisite in the task at hand. As such, assignment of the next task (assignment) by faculty must be such that students possess or could reasonably develop the skills needed to complete the task. This suggests a “scaffolding” approach where the students alternate increases in their competence (skill) and their confidence (self-efficacy), building toward mastery. This concept is developed later in the paper.

However, the alternative possibility of a downward spiral also exists, as described by Bandura,

People who doubt their capabilities shy away from difficult tasks which they view as personal threats. They have low aspirations and weak commitment to the goals they choose to pursue. When faced with difficult tasks, they dwell on their personal deficiencies, on the obstacles they will encounter, and all kinds of adverse outcomes rather than concentrate on how to

perform successfully. They slacken their efforts and give up quickly in the face of difficulties. They are slow to recover their sense of efficacy following failure or setbacks. Because they view insufficient performance as deficient aptitude it does not require much failure for them to lose faith in their capabilities. (Bandura, Self-Efficacy, 1994)

This downward spiral away from mastery is depicted in Figure 2 below.

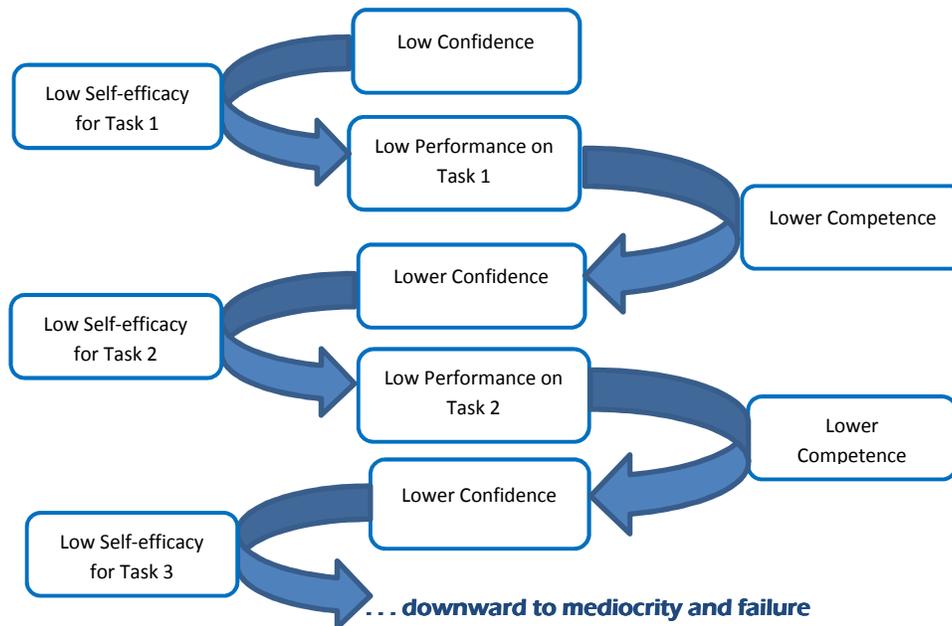


Figure 2 - The Downward Spiral of Higher Confidence and Competence

Which spiral occurs for an individual student working on a specific seeking to master a specific is determined largely by their current state of competence and confidence (based to a large degree on past experiences in this or similar tasks) and the real and perceived degree of difficulty of the task. In fact, the direction, up or down, can be reversed over time and experiences. However, Bandura offers some encouragement regarding the likelihood of reversing an upward spiral to a downward one, “Successes raise efficacy and failure lowers it, but once a strong sense of efficacy is developed, a failure may not have much impact.” (Bandura, Social Foundations of Thought and Action: a social cognitive theory, 1986)

What determines one’s self-efficacy?

When one examines the dynamics of self-efficacy and motivation more deeply it becomes clear that they have enormous impacts on behaviors that are closely related to innovation, such as choice of task and task difficulty (likelihood of success/risk) and persistence. Atkinson provided a useful taxonomy of motivation, asserting that it is dependent on motive, expectancy and incentive, defining each of these as follows:

Motive – “A disposition to strive for a certain kind of satisfaction, as a capacity for satisfaction in the attainment of a certain class of incentives.”

Expectancy – “A cognitive anticipation, usually aroused by cues in a situation, that performance of some act will be followed by a particular consequence.”

Incentive – “relative attractiveness of a specific goal that is offered in a situation (or the relative unattractiveness of an event that might occur as a consequence of some act.” (Atkinson, 1957, pp. 359 - 372)

Each of these has strong relationships to innovation and engineering education. *Motive* could be a drive toward either intrinsic or extrinsic positive motivators (or incentives) or even drive to avoid unattractive consequences. If one fears criticism by either a professor or a boss in a design review, they will be driven to conservative designs rather than innovative ones in order to avoid that undesirable outcome. In fact, each task has two inherent elements of motivation, the positive to achieve success and the negative to avoid failure. “The attractiveness of success is a positive function of the difficulty of the task and that the unattractiveness of failure is a negative function of difficulty.” (Atkinson, 1957) As such, the definition of tasks (assignments, projects, exam questions, . . .) by the engineering faculty member will, to a large degree, determine the relative perceived difficulty and the relative positive or negative motives of the task. If that difficulty is too great, it will drive the student’s motivation toward the negative motivation and conservative solutions. If it is too easy, motivation will be low because the satisfaction of achievement will be low. However, if the task is challenging but achievable, the motivation will be positive and high, yielding the greatest chance of innovation. Of course, the relative difficulty of any assignment depends upon the student’s level of capability (competence) at that point in their development.

Similarly, mapping *expectancy* onto design and engineering education guides the engineering educator in defining assignments with the right level of difficulty. “One cannot anticipate the thrill of a great accomplishment if, as a matter of fact, one faces what seems a very easy task. Nor does an individual experience only a minor sense of pride after some extraordinary feat against what seems to him overwhelming odds.” (Atkinson, 1957) Further, expectancy can have both positive and negative influences on innovation through a link to positive or negative motivation. If one is motivated by achievement of a great outcome, their expectancy for criticism is positive as criticism will aid them in improving their design. However, if their motivation is to avoid criticism as an undesirable outcome, it will lead to stress, reduced performance and designs that are more conservative and less innovative.

Finally, the engineering faculty member also has great influence over *incentive* as an element of the student’s motivational level. As incentives increase the student’s drive toward positive rewards, they trigger more risk-taking, innovative behavior. This is consistent with Pink’s preference for intrinsic motivation in his book *Drive*, discussed below (Pink, 2009). The ultimate intrinsic motivators of mastery and impact on the world were mentioned repeatedly by innovation leaders (Hanifin, 2013) as desirable for innovative behavior. However, if external motivations, such as the loss of points toward a grade, are the dominant incentives, they tend to trigger less risk-taking and more conservative behavior.

This essential combination of confidence and competence is not widely recognized or studied by engineering educators. The following section examines four innovation-related tasks in which this coupling of confidence and capability is magnified to even higher levels: creativity, ethnographic research, teamwork and critiques.

Interdependencies and Interactions of Confidence, Self-efficacy and Innovation Activities

As one examines the relationships between confidence/self-efficacy and innovation, a disturbing irony emerges. Many of the processes and tasks that are inherent to effective innovation are often anxiety producing. To make matter worse, an engineer's performance in these same areas is directly diminished by the resulting fear and insecurity. These areas include creativity, ethnographic research (which involves observing and talking with strangers), presenting one's ideas to peers and superiors, accepting and objectively reflecting on constructive (and non-constructive) criticism, and working on teams with people whom you did not select (and may not like). The more confident and competent one is in performing these tasks, the more effective an innovator he/she is. However, if the inherent anxiety of these tasks diminishes one's confidence, the reduction of competence will follow, leading to yet lower confidence.

An examination of some of these specific processes will help to develop an understanding of the ways in which self-confidence and efficacy (or lack thereof) impacts one's overall capability to innovate. This section will examine four such processes in this context: creativity, ethnographic research, teamwork and critiques.

Creativity: The dependency between confidence and creativity is the subject of a recent book by two leaders in innovation and innovation education, Tom and David Kelley (Kelley, 2013). In fact, even its title, *Creative Confidence*, suggests that dependency. The premise of this dependency is summed up as follows, "With creative confidence, they (people) become comfortable with uncertainty and are able to leap into action. Instead of resigning themselves to the status quo, or what others have told them to do, they are freed to speak their mind and challenge existing ways of doing things. They act with greater courage and have more persistence in tackling obstacles." (p. 10) Conversely, fear and the resulting anxiety and insecurity works directly against our creativity. However, we are not born with fear of being judged, but it develops as we are judged by peers, teachers and parents. Teachers and parents do so yield what they see as better performance and results from children, but in so driving the children to the "right answer" reduce the child's creativity. Children learn to fear the judgment of others and reduce their creativity to reduce the risk of such criticism. Before this metamorphosis to fear, "Most children are naturally daring. They explore new games, meet new people, try new things, and let their imaginations run wild." (Kelley, 2013) p. 53

Other researchers have described a similarly devastating emotional experience of shame and its resulting diminution of creativity "Author and researcher Brene Brown, who has interviewed scores of people about their experiences with shame, found that one third of them could recall a 'creativity scar,' a specific incident where they were told they weren't talented as artists, musicians, writers, singers." (Kelley, 2013) p. 54

Ethnographic Research: The stereotype of the modern engineer is the cartoon character, Dilbert . . . a nerd with few social skills who resides by himself in a cubicle. While personality data is not available, based on personal experience, the author hypothesizes that such stereotypes are, to some degree, self-fulfilling, attracting a significant number of students who tend to be introverts.

The often seek to rely on their mathematical and scientific knowledge and a “can do” attitude to solve problems by themselves.

Such personalities are not supportive of the call from innovation leaders to become anthropologists and to interact directly with customers to discern what delights and frustrates them within a broad design domain (Ten Faces of Innovation, Tom Kelley, Creative Confidence: Tom and David Kelley; Change by Design, Tim Brown). Engineering faculty are sending students out to observe and interview strangers who are using a product or service, asking probing questions of them. For many students, such activities are intimidating and produce anxiety. Faculty members need to be sensitive to the this incongruity between what they are asking students to do and what students are apprehensive and insecure in doing, especially if they are not prepared through clear guidance, controlled exercises and practice in comfortable environments.

Teamwork: Few engineers work alone on anything, including innovation. Rather they work on teams that include other engineers and many other types of professional collaborators. “Creativity is a team sport. Like many elements of creative confidence, building on the ideas of other requires humility. You have to first acknowledge – at least to yourself – that you don’t have all the answers. The upside is that it takes some pressure off you to know you don’t have to generate ideas all on your own.” (Kelley, 2013) p. 103

Such humility and openness requires self-confidence. However, working on teams, like creativity, can also be the source of considerable anxiety and insecurity as individual vie for team leadership, deliberate on both the team design/product and the processes to create that design, and criticize each other on the concepts offered (and react to that criticism with a wide spectrum of emotions). Team members with high degrees of confidence and competence are much more comfortable offering their innovative concepts without fear of the reactions of teammates. This may be due to the confidence that any criticisms will be in error. Those with even higher levels of confidence and commitment to the team may welcome such criticisms as opportunities to improve the design for the good of their team and company.

While team experiences can have a negative impact on an individual’s self-efficacy, another human phenomenon, vicarious support of teammates, can build an individual’s self-efficacy, even when the team’s success is built upon the contributions of other teammates. This influence was described by Gerber as follows, “. . . individuals can build self-efficacy through vicarious learning and social persuasion. Individuals vicariously learn about their ability through observation of the behaviors of others who are similar or those with perceived prestige and competence. The observation becomes a guide for future action, promoting action over apprehension, and discouraging mimicking behaviors that receive negative results. Additionally, individuals build self-efficacy when persuaded by others of their ability to succeed at a given task and given supports to perform successfully.” (Gerber 2012, with reference to Bandura and Walters, “ Self-efficacy: The Exercise of Control” 1991)

Overall, team based activities have an extraordinary potential for both negative and positive effects on the self-efficacy of team members. Thus it is critical that engineering faculty members

fully understand the potential and dangers of teamwork, and pay special attention to how they train students to develop their teamwork competencies and how they observe and intervene to reduce the impact of interactions and behaviors that are counterproductive to building self-efficacy. This is especially true for students who are early in their development and those with little positive experience on teams.

Critique: Perhaps nowhere else in the engineering design process does the emotional impact on confidence/self-efficacy, and consequently on innovation, reach such a high level as in the *design review*. (In some other fields, this is referred to a critique, or *crit* for short.)

Critiques by faculty members have a particularly profound impact on the student's self-concept and self-efficacy. Schunk, in his paper "Self-efficacy and academic motivation" describes the impact of critiques on the broader self-concept, one's collective perceptions about themselves. Self-concepts are formed through experiences with (and interpretations of) their environments and being influenced significantly by reinforcements and evaluations by "significant other persons." (Schunk, 1991) While in college, one's professor is most certainly such a "significant other person," and the quintessential evaluation is the public critique that the professor provided in the classroom.

While encouraging words by the professor can build self-efficacy, those words must reflect the true level of accomplishment of the student, and not inflate the student's accomplishment. "Students often receive persuasory information that they possess the capabilities to perform a task (e.g., "You can do this"). Positive persuasory feedback enhances self-efficacy, but this increase will be temporary if subsequent efforts turn out poorly." (Schunk, 1991)

In 2008 Daniels and Martin published their review of critiques appropriately titled "Critiquing Critiques: A Genre Analysis of Feedback Across Novice to Expert Design Studios." They describe critiques and their inherent impact on students as follows, "Design juries are cornerstones of design education genre in which students present their work and receive feedback, design. As the primarily oral juries (also referred to as critiques and reviews) are high-stake, important events in design students' learning experience. . . . we have learned from notable design scholars that a climate of fear, defensiveness, anxiety, and stress is associated with the feedback that occurs within critiques." (Martin, 2008) Their study points out complex issues of how faculty (and external design juries) must balance the desire to teach competence through their feedback with the need to stimulate creativity and students' confidence as design professionals. The author feels that these same issues are present in the design reviews common to engineering education.

While Daniels and Martin studied and categorized the types of responses employed by faculty members at four levels, they did not evaluate the impact of various responses on students. They did note that "in the novice studio, critics' roles were more about directing students and their designs unequivocally, whereas in upper division studios, their roles were more exploratory." As educators wishing to stimulate creativity, in either design or engineering design, we should be concerned about the negative impacts on confidence and creativity that may occur from being too "directive" in our responses to student's designs early in their education. This may be a natural tendency of faculty members who have graded many designs. As Daniels and Martin suggest,

As a teacher and cross-curricular practitioner, I might carefully consider and reflect on students' learning and improvement to guide my response on my best feedback days. Yet, on other days, I give feedback primarily to justify my grades or avoid grade complaints or continued frustrating interactions with difficult students. Sometimes, even, I provide patterned, almost robotic responses without strategic intent—because I have seen the same mistakes over and over. (Martin, 2008)

While these four anxiety producing elements of the innovative process (creativity, ethnographic research, critiques and teamwork) are discussed above, several others are equally anxiety filled and equally important to innovation. These include viewing failure as an opportunity to learn and maintaining comfort with ambiguity. While these are not discussed herein, they should, like the first four, be considered by educators as critical “tipping points” in the education of innovative engineers.

Mastery and Drive

Two other authors, Daniel Pink and Tony Wagner, provide other insights relevant to the impact of intrinsic motivation on one’s mastery and drive as they relate to creativity and innovation. It is important that engineering faculty understand these insights as they are central actors in building the motivation and drive of their students.

In his book, *Drive: The Surprising Truth About What Motivates Us*, Pink argues convincingly about the superior motivational impact of intrinsic factors over extrinsic factors, especially related to motivation for such objectives as learning, creativity and innovation. (Pink, 2009). Some of the key intrinsic motivators are the inherent joy of doing a job well, mastery of one’s professional skills and knowledge and using those skills to serve the world and humankind. Typical extrinsic motivators are pay, grades and external praise. In fact, extrinsic rewards are not only less effective in motivating than intrinsic rewards, but they can reduce intrinsic motivation . . . “the hidden costs of rewards – extrinsic rewards such as grades, can reduce intrinsic motivations such as the satisfaction of solving a problem, improving the world, . . . and many also reduce such things as creativity, performance and even character.” (Pink, 2009) p. 35

Wagner, in his studies of many effective innovators, *Creating Innovators*, (Wagner, 2012) p. 25 similarly attests to the superior impact of intrinsic motivation applied to innovators. He (like Pink) refers to Dr. Teresa Amabile’s work in creativity, productivity and innovation which asserts that “All forms of motivation do not have the same impact on creativity. In fact, it shows that there are two types of motivation – extrinsic and intrinsic, the latter being far more essential for creativity . . . passion and interest – a person’s internal desire to do something – are what intrinsic motivation is all about.”

The relevance to educating engineers who are more effective innovators is that faculty members must devise educational structures and projects that stimulate students’ intrinsic motivation to

achieve professional mastery and to employ that mastery for impacts on the world that resonate with their personal values. [Pink defines mastery as “the desire to get better and better at something that matters.” (Pink, p. 109)] If this pursuit of mastery for a valued purpose takes root in a student, they will stop focusing on how long the assignment took, but rather they will focus on its success in pursuit of mastery. If it grows further, they may reach the state of *flow*, where their engagement of the task takes over their focus to the point that they are totally consumed in the task, losing track of time and place. The goal becomes self-fulfilling and the activity is its own reward. (Csikszentmihalyi, 2004) As researchers and educators, most engineering faculty members have experienced flow and have derived immense motivation and satisfaction from doing so. It should be a central goal, as engineering educators, to enable our students to do the same.

Viewing Oneself as a World Changer

A vital element of self-efficacy is believing that you can effect change, and the ultimate expression of self-efficacy is believing that you can change the world. Wagner describes this effect through the foundational concepts of Albert Bandura, “As. . . Albert Bandura has shown, our belief systems affect our actions, goals, and perception. Individuals who come to believe that they can effect change are more likely to accomplish what they set out to do. Bandura calls that conviction, “self-efficacy.” People with self-efficacy set their sights higher, try harder, persevere longer, and show more resilience in the face of failure.” Wagner’s book, “Creating Innovators” presents a series of case studies of individuals who grew to see themselves as “world changers” and then became just that. One common experience along that path was the encouraging influence of a significant person (often a faculty member or mentor) who allowed them great freedom in addressing a challenge of social significance. (Wagner, 2012) pp. 9-10

Values-based universities, such as those sponsored by various Catholic orders or other religions, are especially attuned to developing the students’ sense of purpose and connectedness in the world. For example, it is the sole vision of University of Detroit Mercy (UDM), a Jesuit and Mercy institution, to be “distinguished by graduates who lead and serve in their communities.” (University of Detroit Mercy, 2014) Such leading and serving in your community is the stuff of which world changers are made. The core curriculum of UDM, required of all students, develops the student’s personal “meaning and values”, understanding of the “diverse human experience,” and their sense of “social responsibility.” (University of Detroit Mercy, 2014) All of these directly support their confidence, competence and mindset as world changers.

UDM and other universities have also sought to graduate world changers through their involvement in socially significant projects. For example, in the Design for America program at Northwestern University, Gerber, Olsen and Komarek have employed extracurricular design projects, often cast in a major issue with broad societal impact, to stimulate the same sense of personal empowerment in engineering students. They found that through such projects “students build innovation self-efficacy through successful task completion, social persuasion, and vicarious learning in communities of practice with clients, peers, industry professionals, and faculty.” (Gerber, Olson, & Komarek, 2012) Based on the findings of Wagner and Gerber, et al, one of the

very best ways that engineering faculty can develop the innovative confidence of our students is to engage them in projects of real social significance and continually cast other classroom projects in their potential for serving humankind.

Pedagogy and Activities to Develop Confidence and Self-efficacy in Parallel to Innovative Competence and Mastery

Several engineering educators and innovation leaders have recognized how important confidence and self-efficacy are in the development of innovative engineers (Kelleys' Creative Confidence, Liz Gerber DFA, Carberry et al, Baker, et al) and some have begun to develop models and methods for measuring students' self-efficacy for important engineering tasks such as tinkering (Baker) and design (Carberry). Much has been published on classroom "creativity exercises" that stimulate ideation of novel solutions (Felder, ((add other references). However, little has been published on the pedagogy and activities that engineering faculty might employ to aid students in the development of self-efficacy for innovation-critical tasks. The remainder of this paper will address this by suggesting a scaffolding concept to reinforce the "upward spiral" of successive increases in confidence and competence of students, and some specific ways in which this might be applied to key innovation tasks, such as teamwork, ethnographic research, sketching and presentations/critiques (especially design reviews).

[Note: The concepts of the upward spiral and scaffolding are closely related to each other, but not the same. The upward (and downward) spiral is a reinforcing phenomenon that can be triggered intentionally or unintentionally through a myriad of experiences and personal responses. Scaffolding is an educational method designed to trigger and support the student's movement on an upward spiral of confidence (self-efficacy) and competence.]

Scaffolding to Guided Mastery

The most effective way of creating a strong sense of efficacy is through mastery experiences. Successes build a robust belief in one's personal efficacy. Failures undermine it, especially if failures occur before a sense of efficacy is firmly established. (Bandura, Self-Efficacy, 1994)

Figure 1 describes the upward spiral whereby increasing confidence and competence successively support further development of the other. This implies a strategy of "scaffolding" where an engineering faculty member can, through well devised assignments, guidance and responses, enable a student to simultaneously increase his/her self-efficacy and mastery of key tasks that are directly supportive of innovation, such as ethnographic research, creativity and acceptance of critiques. Through this successive stepping to higher levels of competence and confidence, one climbs the scaffold to mastery. As a student becomes more confident regarding such tasks they are more willing to take on more difficult challenges using these skills. In fact, research has shown that this increase in confidence and decrease in anxiety make them more likely to be successful in such challenging tasks.

Atkinson explains this relationship in the bell curve linking motivation and probability of success (see graph on the right). If the task is too easy it is boring and motivation is low. If the task is too hard it is daunting and students expect failure, and motivation is also low. Assignments in the center maximize motivation. As the competence increases, the point on the curve of any specific task (assignment) shifts to the right lowering both difficulty and motivation (and intrinsic joy of mastery), making it necessary for faculty to assign more difficult tasks lest the motivation drop. (Atkinson, 1957)

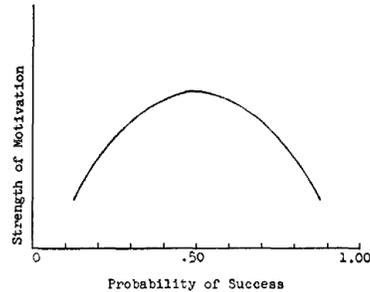


FIG. 1. Strength of motivation to achieve or to avoid failure as a function of the subjective probability of success, i.e., the difficulty of the task.

Atkinson's second graph (right) depicts how very easy or very hard tasks elicit high fear of failure and anxiety. This explains why scaffolding is especially effective when applied to tasks that are naturally anxiety-producing, such as teamwork, creativity and ethnographic research . . . all central to innovation. It also makes it clear that faculty members need to always make the steps on the scaffold the right height, staying in the "sweet spot" of probability of success and motive to achieve. At this point, the positive motive to success overpowers the motive to avoid failure, allowing the student to embrace more innovative alternatives, rather than seeking the safest answer. (Atkinson, 1957)

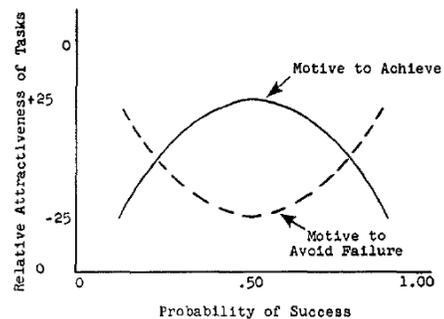


FIG. 2. Relative attractiveness of tasks which differ in subjective probability of success (i.e., in difficulty). The avoidance curve has been inverted to show that very difficult and very easy tasks arouse less fear of failure and hence are less unattractive than moderately difficult tasks.

As the faculty member becomes more aware of and sensitive to the various motivations, expectancies, and incentives available to students, he/she becomes more able to impact student motivation and their comfortable with task ambiguity and risk taking (mitigating fear of failure.) This enables the creativity of engineering students throughout the design process, including design reviews.

Other educational researchers also support and clarify the effectiveness of scaffolding. Schunk employs the research of others to explain how scaffolding works through the successive stair-stepping influence of self-efficacy, motivation and competence, stating "Self-efficacy is substantiated as learners observe goal progress, which conveys they are becoming skillful (Elliott & Dweck, 1988). Providing students with feedback on goal progress also raises self-efficacy (Bandura & Cervone, 1983). Heightened self-efficacy sustains motivation and improves skill development." (Schunk, 1991)

Obviously, scaffolding starts with the first step, and once it's mastered the results can be powerful. However, in all tough challenges, that first step can be the most difficult. We can all remember ourselves or our children paralyzed by fear at the top of the slide or the high dive, and how quickly that fear becomes joy when they bravely let go and experience the joy and satisfaction of the ride. As the Kelleys express it, "The biggest hurdle is going down the slide the first time." Ralph Waldo Emerson expressed it even more strongly, saying "Do the thing you fear

and the death of fear is certain.” While that is not always true, “What matters most in the end, though, is this: your belief in your capacity to create positive change and the courage to take action.” (Kelley, 2013) pp. 63-65

So, faculty members need to realize just how important student success on the first steps of the scaffold is. In fact, those small first steps can be the most important ones to creating innovative engineering graduates. The Kelleys feel that these steps can be even more important, stating “Doubts of one’s creative ability can be cured by guiding people through a series of small successes. And the experience can have a powerful effect on the rest of their lives.” (Kelley, 2013) p. 40

If a faculty member is to support the student’s self-efficacy for a specific task, such as ideation of innovative concepts or presenting their work in front of design juries, he/she should start with smaller tasks upon which students are likely to be successful, employ clear grading rubrics that allow students to assess and see progress, and later provide more difficult tasks that build on the students’ increased competence. Again, Schunk offers valuable perspectives on the mechanisms that affect these, stating “The motivational benefits of goals depend on their properties: proximity, specificity, and difficulty. Proximal (close-at-hand) goals promote self-efficacy and motivation better than distant goals, because students can judge progress toward the former easier than toward the latter. For the same reason, goals that incorporate specific performance standards raise efficacy and motivation better than general goals (e.g., "Do your best"). Pursuing easier goals may enhance efficacy and motivation during the early stages of skill acquisition, but difficult goals are more effective as skills develop because they offer more information about capabilities.” (Schunk, 1991) (Bandura & Schunk, Cultivating Competence, Self-Efficacy, and Intrinsic Interest Through Proximal Self-Motivation, 1981)

After these smaller first steps, once the upward scaffold climb has started towards mastery of engineering and innovation, the challenges (steps) have to become larger so the educational process is kept in the sweet spot of both high motivation and low anxiety.

What Engineering Faculty Members Should Do

If we are to graduate engineers who are more innovative, we need to create a milieu of innovation in our classrooms and employ pedagogy of scaffolding, especially in key anxiety producing tasks of innovation: teamwork, ethnographic research, ideation/creativity and design review.

Create a milieu of innovation

We suspect that if we asked engineering faculty members if they wanted their students to be innovative, most would answer yes. However, many of us focus most of our teaching on solving problems with one “correct answer.” “If thus and such exists and the phenomenon is controlled by this law of physics and that equation, then what will occur?” The beam will bend this much,

the vibration will have this amplitude or that much current will flow. It makes classes orderly and grading structured.

It's only natural for such structured animals as engineering faculty to have predictable reactions to novel responses in class or on tests. It upsets our lecture and messes up our grading, so we react negatively . . . sending a clear message to students who want to get the right answer and the good grade that comes with it . . . CONFORM TO THE PROFESSOR'S IDEA OF WHAT IS *RIGHT*! And students learn quickly to give the professor what he/she is looking for.

What faculty do or say will be seen as challenges or stressor by students. To most of our students, the professors are held in great respect and even awe. Public criticism by anyone brings embarrassment, and public criticism by our professors brings shame . . . shame that begets insecurity, destroying confidence and self-efficacy for the task at hand. Many great innovators have had to overcome the "creativity scars" that resulted from such criticism. "Author and researcher Brene Brown, who has interviewed scores of people about their experiences with shame, found that one third of them could recall a 'creativity scar,' a specific incident where they were told they weren't talented as artists, musicians, writers, singers." (Kelley, 2013)

So, if we want to create a milieu of innovation in our classrooms and offices, we need to change from the all-knowing "sage on the stage," to the collaborative "guide on the side." We need to respond to questions and concepts that are, at first blush, silly, by exploring them with the student and others in the class. Instead of rejecting ideas, we need to engage the class in their consideration, asking questions like "How could we build that?", "How could this be combined with other ideas that we've explored?" or "What are some of the advantages of this idea?" or "What customers would like this idea and why would they like it?" In doing so we will become guides toward mastery, with great positive impact on students' intrinsic motivation, confidence, self-efficacy and, ultimately, their innovative competence.

A person is more likely to not only **be creative** but to decide that **they are a creative person** if they possess a high self-efficacy related to the processes of creativity and innovation. So, if we are to educate more innovative engineering graduates, we must not only create a milieu of innovation, but set about the building of students' self-efficacy in certain tasks that are essential to innovation.

Scaffolding in Key Innovation Tasks

Scaffolding can be done to create self-efficacy in many different areas . . . many of which are inherently stressful and create anxiety in students. These include teamwork, creativity/ideation, ethnographic research/interviewing, reflecting on criticism, building prototypes, . . . The following are offered as concepts to scaffolding for the simultaneous development of competence and self-efficacy for several of these key areas.

Scaffolding for Teamwork

The ability to function well on a design team is a critical element of innovation and especially intrapreneurship. However, conflicting personalities and inconsistent expectations and processes

often block effective communication and creativity of teams. However, faculty members sometimes do little more than assign students to teams and turn them loose on a project. Faculty members can do more to support the scaffolding of confidence and competence on team-base projects. For example:

1. Provide guidance of effective teamwork methods, typical pitfalls, stages and structures.
2. For the first experiences of teamwork, make the teams small (even two students) and short-lived and assign short, simple tasks. Allow students to pick their own teammates.
3. Ask teammates to reflect on how the team worked. Did everyone contribute equally? Did the team listen equally and respectfully to each team member? Do all teammates have the same perceptions regarding such issues?
4. Insist on a “team spirit” that dominates the interactions between team members, including such things as team names, t-shirts, etc. to encourage that spirit.

If team-based experiences are done well it will not only result in independent development of teamwork skills and confidence, but it will result in vicarious influences in which team members build the overall confidence of the team and the individual self-efficacy of all team members.

Scaffolding for Ethnographic Research

Some of the methods to understand the needs and frustrations of customers can be intimidating to students and design practitioners. This is especially true of ethnographic research that involve observation of and discussions with strangers.

The Kelleys offer the following methods of overcoming fear of customer interviews

1. *Be a “fly on the wall” in an online forum*
 2. *Try you own customer service: go through the experience yourself*
 3. *Talking with unexpected experts: the people closest to the product or process may know more about what right and wrong with it*
 4. *Play detective in pursuit of insight: sit with a book or headset where you can watch people use your product or service*
 5. *Interview some customers: prepare a few open ended questions and think of follow up questions, like “Why?” or “Can you tell me more about that?”.*
- (Kelley, 2013) p. 45

The author believes that these ideas, or similar variations, can be applied to student assignments to scaffold students’ competence and confidence for ethnographic research.

Other concepts were offered by Alan Carberry, such as interviewing a classmate or observing people on campus doing something that is the student is familiar with. (Carberry A. , 2014)

Scaffolding for Creativity/Ideation

Starting scaffolding with many small steps before taking large ones is especially appropriate for the tasks of creativity and “ideation”. Way to do so is simply starting with small, easier design projects. The Kelleys offer this guidance: “Building confidence through experience encourages more creative action in the future, which further bolsters confidence. For this reason, we frequently ask students and team members to complete multiple quick design projects rather than

one big one, to maximize the number of learning cycles.” (Kelley, 2013) p. 43 This idea certainly applies to design projects in engineering curriculum. The early ones should be smaller and less risky to build confidence. Projects that can be done in one class period can be followed by one-day projects. Prototypes of design concepts can be made from simple, inexpensive materials that require no special fabrication skills, like paper, Styrofoam, PVC pipes and duct tape.

Adam Carberry has developed an innovative concept for encouraging student creativity. In order to increase student confidence in trying more innovative designs, for each project the team must present two solutions: one that has a high probability for success and one crazy one. And then they are required to apply on part of the crazy solution to the conservative solution. (Carberry A. , 2014)

Scaffolding for Design Reviews

Design reviews, called critiques or “crits” in some fields, are fraught with opportunities to destroy a student’s confidence and self-efficacy regarding their capabilities to design and innovate. Dannels and Martin even describe students who collapsed, or burst into tears, or even became suicidal after severe critiques of their design concepts. (Martin, 2008) While such responses may be rare, we all remember times that classmates or we ourselves were devastated by harsh critiques of our work by faculty members.

Of course the ideal occurs when a faculty member is able build the milieu of creativity, where discussion of design concepts are freely offered and accepted as a natural part of the design process. One step is to teach students how to rigorously engage in brainstorming where any criticism is absolutely forbidden. Another process is for the faculty member to continually dialog with students about their design concepts in one-on-one conversations in a design studio or in their offices, making the discussion and “crit” private and less formal . . . and clearly not one that impact the student’s grade in the project and course.

Regardless of the classroom environment, the formal design review is a time of great opportunity and danger regarding scaffolding of competence and confidence. Here are few suggestions to increase the chances for the student’s moving on an upward spiral

1. Always begin the review of the design with the positive responses. What are the elements that were good, showed creativity, were sound technically, demonstrated understanding of customer wants and needs, build upon previous iterations, products or literature in the product domain, . . .
2. Rather than pointing out the weaknesses of the design (as perceived by the instructor), coach students to observe the things that may lead to improvements of their designs by asking leading questions. Questions like “which elements of your design will be the most responsive to customer needs and wants?” Or, “are there any features that you wanted to incorporate, but were unable to?” Or, “in ‘release 2.0, what improvements might you try to make in product performance, cost or features?”

3. Scale the level of directness and forcefulness to the level and maturity of the student(s). Students who are inexperienced or lack confidence will view criticism as a personal attack and act defensively, so faculty members must tread most carefully with these most vulnerable students. However, students who have climbed the scaffold to build both competence and confidence . . . who have mastered the task at hand . . . will welcome the criticism as a valuable contribution to the quality and robustness of the design . . . in some cases providing improvements and in others honing their case for the product by skillfully and objectively defending their design. As students move toward this higher level of mastery, the design review begins to take on the tone of open and frank dialog between equals.

Conclusions

There are two central conclusions to the findings of this research [a three year study of innovation and intrapreneurship described in the “Background Research” section above and in a previous ASEE Paper (Hanifin, 2013)]. First, engineering faculty members need to reflect and act on the need to develop both the competence and the confidence of their students. Most engineering faculty members were educated in a model that emphasized technical competence as the singular goal, without consideration of the self-efficacy needed to develop the key competences of innovation: creativity, ethnographic research and observation, teamwork, etc. and the mindset that they are “world changers.”

Second, much more research and pedagogical development are needed to explore the methods and pedagogy that develop self-efficacy, such as scaffolding. This research needs to define and measure learning outcomes in areas other than technical competence, and how these are impacted by educational innovations aimed at the development of self-efficacy.

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