AC 2011-1291: THE FIRST-TO-FOURTH FLATLINE: ASSESSING UNDERGRADUATE STUDENTS' CREATIVE CAPACITY

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The First-to-Fourth Flatline: Assessing undergraduate students' creative capacity

Background

Defining Creativity

An underlying premise is that our species is inherently creative, in that we make things and enjoy doing so, and that we are imaginative and take pleasure in originality. Creativity is central and vital in our existence. In the process of making, we have a tendency, perhaps even a drive, to make things better. We not only want to make things, we also want to make things new, striking, surprising, original, more functional and more beautiful.

Why is this? Why are we inherently creative? Perhaps the process of making something, particularly something that will be shared with others and subject to some judgment, causes the cognitive, emotional and physical processes of being imaginative to "go to work." We no doubt evolved with the creative members of our species surviving. Perhaps we retrieve from cognitive archives and stockpiles of experience, merging concepts sometimes from disparate sources, in the service of creativity. This process, with subsequent feedback from public display and personal reflection about the creative process itself, broadens one's experiences, providing further material to stockpile and archive.

Creativity may be our most important human skill. In one sense of the word, to be creative means that *one can make something*, a fundamental human impulse. When we make a cake, draw a diagram, or a write a proposal, we create. We all create, making things that did not exist before. Creativity is also one of our most valued characteristics. In another sense of the word, to be creative means *to be imaginative or original*. We celebrate exemplary creativity at art galleries, concert halls, sports arenas, and auto shows.

Creativity is a *complex*, and a complicated construct to understand. Creativity "represents a highly complex and diffuse construct"[1]. Most people have a general idea of what creativity is, and they can identify something that has its qualities, but they have difficulties when trying to specify a good, ubiquitous definition. Because of the difficulties in defining creativity, authors spend considerable time doing so, sometimes devoting an entire paper[2] or a chapter[3] to the task.

Research in creativity began after[4] gave an interest- and research-spurring presidential address for the American Psychological Association. Since the rise in interest in creativity in the 1950's, the focus of research has been on the *characteristics of the creative person*, a person's *creativity across their lifespan*, the cognitive *process of creativity*, and the *social environments* best suited to creativity[5]. In relation to these areas of focus, creativity is typically defined under the categories of a process, product, or person[6,7], meaning that creativity is happening, it is an end result, and it is descriptive.

This theory embodies the notions of process, product, person and motivation advanced in the literature on defining creativity. That is, a *person* is engaged in the *process* of making a *product* (broadly defined). The person is *motivated* by the enjoyment of the making itself and by the eventual sharing of the product with an audience. Csikszentmihalyi[8] would add that the person must necessarily *have knowledge* of the process and product and corresponding *be dissatisfied* with the current state, thus the driving force to make something new.

Process

Some definitions focus on the process of being creative. Creativity comprises creativity-relevant processes, domain-relevant skills, intelligence, and wisdom[9,10]. Sternberg[11] developed his theory of creativity to describe wisdom balancing intelligence and creativity so that "intelligence represents a thesis, creativity an antithesis, and wisdom a synthesis." Csikszentmihalyi[12] presents that there are three components, the domain, field, and person, which collectively allow creativity to occur. Although many different theories have arisen, this variety helps add to "a new and more encompassing understanding of certain aspects of people's creative efforts"[13]. With the variety though, Mumford cautions to not exclusively use one theory, to not equate all methods, and to continue to refine and develop old methods and theories.

Product

Another definition of creativity focuses on the products of creativity, as labeled by "appropriate observers [who] independently agree it is creative"[14]. Mumford[15] stated that "the ultimate concern in studies of creativity is the production of novel, socially valued products" and that "creativity is a complex phenomenon involving the operation of multiple influences as we move from initial generation of an idea to delivery of an innovative new product"[16]. Thus creativity explains a mechanism of innovation, as innovation does not come out of nothing; it is an act of combination[17]. Product assessments are an example of using this definition of creativity because people are often evaluated on the creativeness of the products they have made or are making. Individual teachers informally do most of these evaluations through general observation, but sometimes the testing is done through formal assessments[18]. Creativity may be domain specific though[19,20] thus requiring assessment in multiple domains.

Person

When studying creativity in regards to its description of the person, researchers look at the person's abilities, traits, and personality. Creative people have the ability to use heuristics for producing ideas, have a hard working style, and have appropriate cognitive styles that categorize, generate new combinations, persevere through difficult problems and dry spells, and tolerate ambiguity[21,22]. Also, they have associational abilities[23], analogical and metaphorical abilities, and imagery abilities[24]. Some say that creativity relates to Eysenck's personality aspects of extraversion and psychoticism because they tap aspects of disinhibitition[25].

Motivation

One of the important traits of a creative person is their intrinsic motivation. Intrinsic motivation always benefits creativity, but depending on the type of extrinsic motivation, creativity can be helped or harmed. Extrinsic motivation that controls tends to be harmful, such as when creative work is evaluated, watched by others, or when there is competition, but extrinsic motivation that enables tends to be helpful, especially if intrinsic motivation is also high. This enabling, extrinsic motivation includes instruction on how to be more creative, with non-contingent rewards, and informative, constructive evaluation[26,27].

Demand for creativity

Depending upon whom you read the world is flat[28], we are part of a rising creative class[29], or the successful professional needs a whole new (creative) mind[30]. Regardless who you believe, there seems to be growing consensus that professionals in developed economies need to be more creative to stay ahead and drive innovations in an increasingly global economy.

The World is Flat[31] made it clear to the general public that routine engineering is now done efficiently in India, China, and other locations. The educational preparation of students for those jobs may also be done globally, potentially dislodging the US as the preeminent place for post-secondary study. What is it that postmodern US universities can offer that is unique and excellent? What will future graduates be prepared to *do* that distinguishes them from others and prepares them to deal with the huge challenges ahead? One answer: the ability for personal creativity and the ability to envision—and to lead others in—innovation and change. Creative competence, including establishing a mindset for innovation, and having the wherewithal to articulate and execute a vision, is essential for technical leadership in the future.

Further, enhancement of creativity contributes to personal fulfillment. To realize and enjoy the full human experience, individuals would do well to cultivate their personal creativity, and in some cases to help others in doing so as well. Many students are drawn to engineering because they are creative or want to be. By understanding creativity better and teaching it more effectively we will attract and retain students.

Efforts to enhance creativity can be expected to benefit all students, and perhaps to help with engineering retention. When assessing creativity, women and men perform equally well[32,33] as do various ethnicities[34]. Although some *intelligence tests* show ethnic differences, particularly in lower test scores for African Americans and Hispanic Americans, these differences do not arise in *creativity assessments*[35]. Instead, *African Americans show higher levels of creativity* because they “have a cultural value of, and tendency toward, creativity . . . [and are] more likely than European Americans to be spontaneous, flexible and open-minded”[36]. So, offering an environment welcoming of creativity and its enhancement, may increase retention rates of females and students of color in engineering.

Individuals naturally vary in their innate creative abilities. Some research shows that those with higher abilities respond better to training[37]. This follows the notion that intrinsic motivation is a distinguisher between those with above average and below average creative ability[38]. As individuals of high ability, engineering students are prime candidates for creativity enhancement. Therefore all engineering students approaching the opportunity of enhancing their creativity, no matter gender, ethnicity, or discipline, would benefit.

Deficiency of Creativity

Creativity is critical for all engineers of the future. Current pedagogical models in engineering are rooted in the past, however, leaving students little prepared to meet these demands. Students are given an arsenal of formulas over the course of their undergraduate years. But, when required to use their knowledge productively in "real-world" contexts during senior capstone projects, it quickly becomes apparent that wider skill sets are needed. Informed by the philosophical reflection that has facilitated previous paradigmatic shifts, we might consider that, in addition to applying basic math, science, and design skills, students also need to cultivate qualitative skills such as asking questions, qualitative modeling, brainstorming, decomposing solutions, presenting, and reporting[39,40].

These are just some of the skills that comprise a student's creative competence, which ultimately includes establishing a mindset for innovation, and having the wherewithal to articulate and execute a vision[41]. Researchers have argued that creative competence can be enhanced[42,43,44,45]. How it can be enhanced is still a mystery. Given the richness and complexity of the contexts in which aspiring engineers are preparing to enter, now is the time to solve that mystery. This project is part of a larger effort targeted at curriculum reform efforts that will improve students' capacity to make meaningful contributions in an ever-changing world.

Engineering education needs to respond to the current era by turning out a larger numbers of engineers capable of being creators, particularly *category creators*—creators of whole new categories of products and services. This *creativity imperative* of our times suggests that a rigorous yet broadly interdisciplinary study of the nature, pedagogy, and enhancement of engineering creativity should be timely and welcome. The remainder of this document describes a project that draws from results in organizational behavior, artificial intelligence, philosophy, and educational theory, to mount a broad initiative designed to vastly improve our understanding of engineering creativity and our ability to enhance or improve it in the classroom and in the field.

Before giving the impression that students are incapable of doing anything, it is important to note that they *can* do what they were trained to do. They can solve equations and size components of existing categories of technology that they have been trained to improve. But the beauty of the traditional, industrial-based, senior design course is that few companies are willing to spend cash (currently ~ $8-10K per project) to have students do routine component or system design. Generally, companies come to the course with projects they have tried and failed to solve. As such, the course is a good testbed to see if you've trained a *creative problem solver,* and the tale of woe above suggests that the traditional curriculum falls short.

Some may assert that creativity is innate and cannot be taught; a person either has natural creativity, or does not. However, similar to doing math, throwing a football, or managing an organization, creativity has *both* innate and developed components. At our colleges and universities, we have significant programs to help students further develop their innate skills in math, football, and management. With regard to creativity, engineering educators are behind where we could be, and we could be a world leader in creativity education.

The Current Study

Given current, post-war models of engineering education, we hypothesized that, despite the need for creative capacity in rapidly-changing global markets, graduating seniors might actually be less creative than their freshmen engineering cohorts. In other words, we theorized that current models of engineering education do not foster creativity, and may actually stifle creativity.

Creative development, capacity, and identity among engineering students are examined in this study as part of a larger effort to maximize creative enhancement in engineering studies. Funded by NSF's IEECI program, we embarked on this study as a jumping point for a larger research effort aimed at improving engineering education by preparing breakthrough innovators, rather than simply training competent engineers.

Our efforts have focused primarily on measuring engineering student creativity. We hope to establish a baseline of where students are now in terms of their creativity to guide our efforts in improving engineering education. We are working with the philosophy that students need to develop a broader and deeper set of skills and dispositions than the current post-war model of engineering education currently instills to better prepare them for innovative activity/productivity long-term.

The understanding gained from the study about creative change will inform the teaching and learning process, particularly instructional design and methodology. We expect the results of this work to inform the body of knowledge about creativity enhancement, including what is important and why. The results also provide a framework for the teaching of creativity to large numbers of students and provide data to assist in decision making regarding whether instruction of creativity will earn a more established position in the curriculum. Creativity is vital to developing student talent, solving the big problems of the world, and achieving individual fulfillment. This study ultimately aims to impact the creativity, innovation, and visionary leadership of the future engineers, while enhancing their personal satisfaction.

We are working with a sufficiency model – that everyone has creative capacity. What we hope to understand through the current assessment cycle is how creative students are and how engineering curricula impact creativity, as a means of informing future research about how to maximize creative capacity and output.

Methods

We have assessed the creativity of about 200 first- and fourth-year engineering students. We have also interviewed students to determine how they view creativity, how their creativity was developed, and how creativity has influenced transition experiences in graduate school and industry. A description of the instruments, recruitment and sampling, administration, scoring and feedback follows[46].

Instruments

The assessment battery was comprised of four instruments, including a demographic survey, the Kirton Adaption Innovation Inventory (KAI)[47], the Abbreviated Torrance Test for Adults[48] (ATTA), and the Innovator Self-Assessment Survey. The previously validated KAI and the ATTA were chosen for the attributes and characteristics they were designed to measure, and because the nationally-normed data suggested that members of different demographic groups performed similarly on the instruments. The data collected with the Innovator Survey is being used to test the ongoing development and refinement of the instrument, as well as to test its validity and reliability. Interviews were also conducted.

Demographic survey

A short survey asked students their names (used only for coding purposes), class standing, race and national origin, gender, and major area of study. The survey also included items we hoped would help us very generally access students' creative identity or experience with creativity during their undergraduate experience. We asked to what extent students considered themselves creative, if their major courses had allowed them to be creative, if they make time for creative activities, and if college has helped them to become more creative.

KAI

The KAI assessment is formatted as a survey of 33 Likert scaled items that ask respondents to think about their level of agreement with particular cognitive styles. Put another way, items give a brief description of a person's attitude toward or approach to work/tasks and respondents mark on an ordinal scale the extent to which they engage similarly to the description provided. Each item corresponds to one of three broad process dimensions: 1) *rule/group conformity*, a measure of tendencies to adhere to or work around rules and structures when problem solving; 2) *efficiency*, a measure of tendencies toward detail and thoroughness; and 3) *sufficiency vs. proliferation of ideas*, a measure of tendencies toward acting on a few good ideas that seem relevant to the problem or generating multiple ideas that could change the way the problem is seen[49].

Total scores on the KAI correspond to a polar scale with 'adaptors' toward one end and 'innovators' toward the other. Adaptors are described as people that accept constraints and learn how to work within the system to find quick and efficient solutions. Innovators are described as people that come up with new ideas that seem to be outside of the norm or that challenge the system. They redefine problems in order to solve them. Because of the perceived differences between adaptors and innovators, it is posited that adaptors and innovators find it challenging to work with one another, and the challenge is greater the further apart their scores. A third category, 'bridgers', are people whose scores fall somewhere in the middle. Because they have attributes of both adaptors and innovators, bridgers reportedly have the ability to bring the two groups together. Note that the spectrum categories are not absolute. Intended in part to facilitate decision-making, performance, and relationships in groups, KAI labels are context dependent, changing with the make-up of a group. For example, a bridger in a balanced adaptor-innovator group may be an adaptor in a highly innovative group. Innovation and adaptation align with two working definitions of creativity: innovation relates to the having of new ideas, while adaptation relates to bringing ideas into being.

ATTA

The ATTA differs from the KAI in that, rather than describing how one approaches a task, respondents are asked to complete three tasks, one verbal and two drawing. The tasks include a list of challenges one might face in an unusual situation and the elaborations on incomplete figures and a series of similar shapes.

The total score of the ATTA is described as a "creativity index." This measure is meant to reflect a person's level of creativity. Recognizing that creativity is complex and multi-faceted, four sub-scales are also reported. The scales are meant to reflect capacities for *fluency*, the ability to generate multiple, relevant ideas; *originality*, the ability to create new ideas; *elaboration*, the ability to build on core ideas through elaboration and detail; and *flexibility*, the ability to perceive one thing in multiple ways.

The use of the ATTA is a slight deviation from our original proposal. Upon additional investigation, we decided to use the ATTA rather than the Torrance Test of Creative Thinking (TTCT). The longer TTCT is used with people of all ages but seems to be tailored more toward K-12 populations. Pulling activities from the validated TTCT, the ATTA has been tailored more toward higher education/adult populations, and hence more appropriate to our current research study.

Recruitment and Sampling

Before any recruitment activities were conducted, members of the research team met with the Deans' Student Advisory Committee, an engineering student leadership group, to discuss the study, possible benefits, scheduling, best recruitment tactics, and possible incentives. It was decided that multiple sessions offered on different days and times early in the semester would be best, that students should be contacted by email, and that incentives, especially food, would be welcomed.

Email contacts were sent from the Dean's office to all first and fourth year engineering students. The email included a brief description of the study and possible benefits, an invitation to students to participate, and a note about possible incentives. Student volunteers in the first year were given four sessions to choose from, and student volunteers in the second year were given seven sessions to choose from. Sessions were scheduled on different days of the week and at different times of the day in order to accommodate students' class schedules and maximize the number of students that would potentially be able to participate. Respondents received an additional email confirming the date, time, and location for the assessment session they had selected.

Based on our first year experience, we thought it might be valuable to make connections with Engineering 101 instructors to promote the study. Connections were made with the instructors of three Engineering 101 sections, all of which were associated with a new curriculum reform effort in the college. We were given class time to solicit freshmen volunteers and administer assessments. In these class sessions, we were careful to emphasize that participation was completely voluntary, that students were free to leave if they chose, or were free to take the assessments without participating in the study. We also emphasized that their participation/non-participation would not affect their course grades in any way. A few students did choose to leave. Most stayed.

In total, 213 first- and fourth-year engineering students participated in the study. According to self-reported data, students racially identified as Asian (n=52) Black/African American (n=3), Caucasian/White (n=102), East Indian (n=11), Hispanic (n=7), and Mixed/Multi (n=5). Students also identified countries of national origin in regions including the USA (146), Middle East (14), China (12), Southeast Asia (10), and other (5). Reported gender identification included female (65) and male (140). Students reported class standings of fourth-year (78) and first-year (132).

Administration

The KAI and ATTA were administered in campus buildings, with each administration monitored by one, two, or three members of the research team (depending on the number of student participants in a particular session), and participants met in a large conference room. Informed consent forms, demographic survey, KAI, and ATTA were distributed. A member of the research team briefly described the study and its purpose. Students were instructed to read the statement of informed consent and sign and date it if they agreed to have their data included in the study. Students then completed the demographic survey and submitted it. When all surveys were complete, brief instructions were given and an opportunity to ask questions provided before students were asked to start the KAI. The KAI survey is not timed but students took an average of about 12 minutes to complete the items. When all the students had completed the KAI, Each of the three ATTA tasks is timed for three minutes with a short pause and brief instructions between each activity. The total instrument took 10-11 minutes to complete. Students then handed both assessments back to the research team member. In the first year, students then followed a member of the research team to a computer lab in the same building. Students were instructed to log on and then complete the innovators survey. Due to changes in computer lab policy regarding research activities, second-year participants were given a handout with the survey URL and were asked to complete it on their own as soon as possible. The innovators survey was the longest instrument used, comprised of about 67 items, and took students anywhere from 5-12 minutes to complete.

Scoring

The KAI is administered on carbon paper. Students' responses are automatically recorded on the hidden scoring sheet behind the instrument. Scores were tallied and recorded by members of the research team under the guidance of a Kirton-certified professional. The verbal and figural activities in the ATTA are analyzed and scored using a rich rubric covering attributes such as emotion, humor, movement, and openness. Three members of the research team were trained in scoring these assessments. They compared and contrasted scores for inter-rater reliability. Scores of the innovators survey were automatically tallied and recorded by the web-based tools used to administer the instrument.

Feedback

In year one, individual results were distributed to participants via email. Along with their individual results on the KAI and ATTA, students were given a packet (at the time of administration) that allowed participants to interpret their results and an additional handout (via email) that detailed how to interpret the meaning of and understand both the KAI and ATTA, along with additional information about the development of the innovators instrument.

Based on feedback we received from students in the follow-up interviews, the feedback process in year two included face-to-face feedback sessions that lasted 45 minutes to an hour. During these sessions, members of the research team distributed individual results as well as handouts to help the students interpret the meaning of and understand their results. Sessions also included lecture, discussion, and Q&A about the research study and instruments, providing students with additional scaffolding to understand and interpret their individual results.

Results

KAI and ATTA

Data analysis

Descriptive statistics (mean and standard deviation) for first- and fourth-year students were calculated for total scores on the KAI and ATTA and examined using SPSS (v.17). In addition, descriptive statistics were also calculated within and across groups using other demographics including race, gender and nationality. Independent group t-tests were conducted to test for significant differences between first- and fourth- year scores on the ATTA and KAI and where appropriate, standardized differences were calculated. A 'standardized difference' is a measure of the magnitude of difference between the mean of two groups, measured in terms of how many (averaged) standard deviations. Finally, correlations (total, within class and gender) were calculated for total KAI and ATTA scores. For the sake of brevity, only key findings related to the goals of this study are reported here. Additional findings may be available upon request.

KAI

According to Kirton[50], the total population mean on the KAI is approximately 95 on a 160-point scale, with engineers generally falling close to that with average total scores ranging between 95 and97 points. In our sample, the first-year mean was 97.1; the fourth-year mean was 100.2.Although these means fall just above the national sample, the difference between the two groups is not significant (See Table 1). Additionally analyses found no significant differences for other demographics (including gender, race, and nationality) within- or between- groups on the KAI. These findings confirm our previous experiences and validation studies[51] which suggest is the KAI stronger of the two instruments.

ATTA

The average nationally-normed sample scores on ATTA range 68-73 (below average range, 60-67)[52]. In our sample, scores fell within that range with a first-year mean total score of 67.7 and 71.4 for fourth-year students. These means also yielded significant differences between the groups (t_{183}*=-2.614, p=0.1, standardized difference=0.40*). 1. Additional analyses revealed that male senior engineering student ATTA score were significantly higher than male freshmen engineering student ATTA scores, (t_{122}*=-2.144, p=0.34; standardized difference* = 0.41) (see Table 1). As with the KAI, no other significant differences were found testing for within- and between-groups differences for other demographics (including gender, race, and nationality) on the ATTA.

Table 1
Comparison of first- and fourth-year students on ATTA and KAI

	Average Total scores (Mean and Standard Deviation)					
	First-year students			Fourth-year students		
	All students	Males	Females	All students	Males	Females
ATTA	67.74 (8.95)	68.94 (8.53)	67.35 (9.13)	71.35 (9.03)	71.24 (10.26)	71.39 (7.83)
KAI	97.09 (14.57)	97.44 (15.18)	97.00 (14.45)	100.24 (15.62)	102.02 (16.0)	97.58 (14.50)

We think the significant differences between first- and fourth-year engineering student scores may also attributed to at least two factors. First, additional analyses revealed that a group of first-year students (n=57) who were enrolled in a cohort piloting a new curriculum program scored lower than the average total score for first-year students (mean=65.8) yielding a nearly over one-half standard deviation difference between the new program and fourth-students. (*standardized difference* = 0.63). We also suspect that the significant differences may reflect a bit of self-selection bias in the sample, the cohort students having taken the assessments during class time and non-cohort students choosing to participate on their own time in response to an email request for volunteers for a creativity study. (If anything, this indicator might confirm our conclusions, indicating that the engineering student population may score even lower than our self-selected sample.) But, again, there were no differences in first- and fourth-year results on the arguably stronger KAI instrument, so any bias leading to differences on the ATTA are likely slight.

Differences in Major Emphasis

Descriptive analyses indicated that students may be performing differently on the KAI based upon their major emphases. For example, the average total score for civil engineering majors (mean=90.2, sd=15.1, *n*=25,) is is approximately 20 points lower than the total score mean for general engineering majors (mean=110.6, sd=14.0, *n*=11,). While these mean differences are intriguing, sample sizes across all 13 represented majors were not large enough for a robust testof significant differences in assessment scores, thus, it would not be prudent to draw any specific conclusions. As our research continues, we will look for additional differences across majors, as well as possible explanations for any differences we might find. (Tests based on demographics including race, nationality, and gender within and across class, did not yield any other significant results.)

Correlations

Between-assessment Correlations

Small to moderate (r=0.2-0.5) correlations were found between KAI and ATTA scores for select groups of students. In the fourth-year sample, KAI and ATTA scores were mildly correlated (r=.284) but first-year KAI and ATTA scores were not correlated. Male fourth-year KAI and ATTA scores were more moderately correlated (r=0.413). but female fourth-year KAI and ATTA scores did not correlate Female first-year KAI and ATTA scores were moderately correlated (r=.323), but male first-year KAI and ATTA scores did not correlate (see table 2). Based on the moderate correlations present in different levels of class and gender, multivariate analyses of variance (MANOVA) were conducted to test for interactions between class and gender on the KAI and ATTA but no significance was found.

Table 2
Correlations between ATTA and KAI for select groups of students

	All Students	First Year			Fourth-year		
		All	Males	Females	All	Males	Females
Correlation	0.284	.271	.323	.254	.294	.413	.160

Assessments and Self-reported Creativity Data

We also correlated four self-report, Likert-scaled items about student creativity with each other and total scores on KAI and ATTA. Among fourth-year students, the KAI correlates moderately with "I am a creative person" (r=.417) and "I make time for creative activities" (r=.314). Within items, "I am a creative person" moderately correlates with "I make time for creative activities" (r=.382) and, "College has helped me to become more creative" correlates moderately with "I make time for creative activities” (r=.284) (See table 3). Among first-year students, "I make time for creative activities" correlates moderately with "I am a creative person" (.522) and "My major courses allow me to be creative" (.297). Also, "College has helped me to become more creative" correlates moderately with "My major courses allow me to be creative" (.369) (See table 4).

Table 3
Correlations for
fourth-year students

	I am a creative person	My major courses allow me to be creative	I make time for creative activities	College has helped me to become more creative	KAI Total
My major courses allow me to be creative	.249				
I make time for creative activities	.382	-.129			
College has helped me to become more creative	.127	.448	.284		
KAI_Total	.417	-.042	.314	-.078	
ATTA_total	.233	.094	.168	.193	.294

Table 4
Correlations for
first-year students

	I am a creative person	My major courses allow me to be creative	I make time for creative activities	College has helped me to become more creative	KAI Total
My major courses allow me to be creative	.115				
I make time for creative activities	.522	.297			
College has helped me to become more creative	.102	.369	.233		
KAI_Total	.271	.016	.268	.114	
ATTA_total	.214	-.084	.114	-.032	.271

Discussion

We theorized that current models of engineering education do not foster creativity, and may actually stifle creativity. The findings of the current study confirm these suspicions to some degree, suggesting that, over the course of their college education, engineering students do not experience a dramatic change in creativity as measured by the KAI and ATTA. In other words, we found that, though students' creativity may not be *hindered* by the current engineering curriculum, neither is their creativity *enhanced*. It seems then that current curriculum models create a creative capacity flatline between the first and fourth years. Future studies should address how the flatline phenomenon in engineering compares to other disciplines, how engineering curriculum reform might help students become frontline innovators, and how more authentic creative capacity measures might be developed.

Flatline in Other Fields?

For the sake of the engineering curriculum, we recommend researching changes in student creativity in other disciplines. Is the flatline phenomenon unique to engineering? Are there disciplines that are effectively enhancing creativity? Looking into disciplines, such as science, technology, and mathematics, will be essential. We also plan to look into fields that are seemingly unrelated, with a focus on those fields traditionally labeled 'creative', such as advertising, visual and performing arts, and creative writing. Through this research, we hope to learn effective approaches, techniques, and strategies for creativity enhancement that can inform meaningful change in the engineering curriculum.

Engineering Curriculum Reform

Again, working under the assumption that creativity can be enhanced, we are already exploring the most effective practices for creativity development. Two activities are worth mentioning here. The first is the development of a comprehensive curriculum reform program. We have worked with colleagues across our college and university to develop a curriculum reform incubator. With a growing cohort of entering freshmen (around 80 students last year and approximately 300 students this year), we are encouraging students through coursework, projects, and explorative dialogue to become category creators, not just technical proficient. The second is the development of two creativity courses, offered from our engineering college to students from across campus. In the introductory course, students learn how to develop their own creative capacity through divergent thinking exercises, bio-creativity activities, journaling, and other individual and group projects. The advanced course, built on the assumption that the best way to learn is to teach[53], students learn how to help others enhance creative capacity.

Creativity Assessment

In addition to measuring student creativity and exploring paths for creativity enhancement, part of our study has also focused on methods of creativity assessment. We are somewhat skeptical of the measures we have used to date. For example, a commonsense comparison of responses to figural, drawing activities in the ATTA would suggest a total lack of creativity from one student, whose strict adherence to the verbal instructions to the point that no divergent thinking or elaborations were evident, and an abundance of creativity from another student, who elaborated in the drawing and used abstractness in the titles. However, following the complex, thorough ATTA scoring guide, the less than creative figures may score higher than the elaborate, out-of the-box figures. Based on our findings and our additional research, we are working to develop a creativity assessment based on attributes exhibited by serial innovators.

We are also starting to question the wisdom of attempting to quantify the complex set of skills and dispositions known as "creativity". Fritz[54] explores the notion of creating as a path to creativity. Similarly, Feinstein[55] proposes a theory of creative development centered on *creative interest* and three steps: formation of a creative interest, exploring the interest, and defining and executing projects rooted in the interest. These processes are not easily captured reflectively in hindsight as is demanded by most paper and pencil-style assessments. As we move forward, we would like to explore more qualitative approaches to assessing creativity, approaches that will likely focus on student strengths and productivity, tapping into motivation, talent, passion, and opportunity as an alternative to psychometric measures To that end, we have secured a grant from the National Science Foundation to develop more effective creativity assessments, moving beyond traditional paper and pencil-style measures to explore real-time, in-action indicators.

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