Creativity Activities in a Design Course Fail to Elicit Gains in Creativity Over and Above those Elicited by the Design Course Itself

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Engineering educators often look to imbue students with qualities beyond purely cognitive skills. Among these are *self-efficacy*, a psychological construct, and *creativity*, a pseudo-cognitive construct. We showed previously that a project-based design course is associated with improvements in both of these constructs without overt training in either. We sought to determine whether overt training in *creativity* can cause similar gains. Students were enrolled in either a fall or a spring section of a BME design course based on development of software and fabrication skills rather than in project-based design. One of the sections included daily, brief *creativity* exercises with non-academic rewards. We found that while this skills-based course was associated with semester-long improvements in *creativity* and *self-efficacy,* overt training in creative thinking did not bring about additional improvements.

Introduction

The accumulation of hard skills, retention of knowledge, and the conceptual understanding of material are largely cognitive traits, and are only one part of what engineering educators hope to achieve. Other traits that are highly valued in engineering are psychological or pseudo-cognitive rather than purely cognitive: *self-efficacy*, *curiosity*, and *grit* (perseverance). *Creativity*, a pseudo-cognitive construct, is likewise cited as a desirable trait among engineers. In previous work we showed that a project-based design course rich in brainstorming activities resulted in a semester-long improvement in certain aspects of *creativity* compared to a course that was relatively poor in brainstorming activities [1]. Not all design courses, however, are equal in the degree to which they are project-based. This led us to question whether overt training in creativity could yield even greater improvements in *creativity* than are already gained in a skills-based design course.

A common perspective on *creativity* is that it is represented by *divergent thinking*, a cognitive construct attributed to J.P. Guilford [2] that describes the generation of many ideas in response to a stimulus. A full review of the extensive field of creativity is beyond the scope of this manuscript. However, an extensive meta-analysis [3] showed, as had others before it, that overt training in *divergent thinking* does indeed result in improvements in that construct with small to moderate effect sizes. Likewise, training in "cognitive core processes," [4] which are parallels of the engineering design process, also result in improvements in *divergent thinking*, and likewise with small to moderate effect sizes [3].

Thus, it is generally accepted that *creativity* can be "taught," either deliberately or organically [5]. Sternberg and Williams recommend several approaches to promoting creativity through pedagogy [6], among these being:

1. Building self-efficacy (self-perceived ability to successfully engage in a task)
2. Encouraging idea generation
3. Instructing and assessing creativity
4. Rewarding creative ideas and products

We enacted in a design class the above four approaches to promoting the development of creative thinking. Students were enrolled in either a fall or a spring section of a BME design course based on development of software and fabrication skills. One of the sections included daily, brief *creativity* exercises with non-academic rewards. On the first day of class and during the final practicum we assessed multiple domains of *creativity*, as well as *engineering design self-efficacy*. *Self-efficacy* is an individual belief in one's ability to attain successful outcomes. It is positively correlated with successful academic outcomes [7], and *engineering design self-efficacy* has been shown by us previously to improve during either project- and skills-based design courses [8]. We find that while this design course was associated with large semester-long improvements both in *creativity* and *self-efficacy,* direct training in creative thinking did not bring about additional improvements.

Study Design

Classroom setting: A second-year design course in biomedical engineering at the University of Virginia was delivered in both the fall and spring semesters of the 2017-18 academic year, each semester by the same instructor. This course focuses on development of skills for the late stages of the engineering design process - prototyping, testing, and iteration – and was shown to increase *engineering design self-efficacy* [8]. Individual training was provided in a variety of fabrication techniques and other skills that we judge to be valuable to the engineering design process as it pertains to medical devices. These included:

1. Embedded controllers and basic electronics
2. CAD, mechanical drawings, and FE simulation
3. 3D printing
4. Soldering and de-soldering of circuits
5. Reducing soft stock material (table saws, circular saws)
6. Forming and shaping soft materials (band saws, jig saws, drill presses, sanders)
7. Reference management software
8. Efficient use of word processing features

For each of these skills, students were given a task and a tolerance (or other minimal goal), and were required to repeat the task until it was completed to specification. Additional training was provided as needed in forming and shaping of metals (horizontal band saws, drill presses, grinders, tap and die), use of laser cutters, solvent welding, and MIG welding. The goal was to gain competence, not mastery, so as to instill general prototyping skills, and to improve student confidence in engaging in those activities (*self-efficacy*).

The course culminated in a 2-week closed-ended design problem – to design and build a simple intravenous infusion pump (peristaltic pump) using the provided components of a microcontroller project board, stepper motor, motor driver, and LCD display with push buttons. Students had the option of designing either rotary or linear peristaltic pumps. Students designed and fabricated all the components that were not provided to them, along with a simple case for the device, and wrote the necessary firmware to control the pump and display relevant infusion parameters.

Assessments: Psychometric assessments were delivered twice – once on the first day of classes and again during the final exam week.

Creativity: The "circles and squares" variant of the Torrance Test of Creative Thinking [9] was used to assess four domains of creative thinking [10] in response to a stimulus:

1. *Fluency* refers to the number of ideas generated,
2. *Flexibility* the number of categorically different ideas,
3. *Originality* the rarity of the response relative to average, and
4. *Elaboration* the amount of detail in a response.

Students were given a sheet of paper with 42 identical circles in a 6×7 matrix. They were instructed "Use these circles as a basis for drawing. Draw for 3 minutes." Figural tests of creativity have been found to have good reliability and validity [11]. To score the responses for *originality*, all the assessments were combined - those taken at the beginning and at the end of the course, and from both semesters of the course (with and without academic advising). We ranked the responses according to originality relative to the entire group, and divided them into five groups with equal numbers of responses, forcing us to use the entire 1-5 scale. The responses were subsequently rank-ordered for elaboration. This process ensured that we assigned scores relative to the two groups as a whole. In contrast, *fluency* and *flexibility* were simple counts and therefore not relative. We did not examine *elaboration* because it is not a fully independent metric from *fluency*; in a time-limited assessment, time spent adding detail detracts from time spent on creating multiple products.

Engineering design self-efficacy: The self-perceived ability to engage in engineering tasks was measured using the 36-item "Engineering design self-efficacy instrument" [12] – that is, whether students feel:

1. *Able*, and
2. *Motivated* to engage in certain engineering design tasks, whether they will be
3. *Successful* in doing so, and how
4. *Apprehensive* they would be in performing such tasks.

These tasks included:

1. Conduct engineering design
2. Identify a need
3. Conduct research
4. Develop solutions
5. Select the best design
6. Prototype the solution
7. Test a design
8. Communicate
9. Iterate the process

A three-level Likert scale was used for each of these to indicate their level of ability, motivation, likelihood of success, and level of apprehension (low-medium-high).

The instrument for *self-efficacy* was delivered online, whereas the instrument for *creativity* was delivered on paper. The creativity instrument was delivered this way both to enforce time restrictions, and because paper is a more amenable medium for drawing than is the typical computer.

Intervention: The spring and fall sections of the course were taught by the same instructor. The principle difference between the sections was the fall (intervention) included overt, daily training in creativity. This training included exercises similar to the creative thinking test described below. Examples include:

1. Listing ideas evoked by a repeating sound;
2. Incomplete figure tasks (excepting “circles and squares”);
3. Alternative use tasks (listing different, unintended uses for a common item);
4. Listing ideas evoked by a particular color;
5. Listing what an abstract figure might represent.

These daily exercises were typically completed on a note card, and they encompassed approximately 2/3 of the fall semester. These exercises were impractical to administer during days spent in workshops. The spring semester served as our control group.

To promote engagement in these activities, and to reward creative ideas and products (see the introductory paragraphs), the instructor offered a cash award each day for one of the first three domains of creativity. For *fluency* and for *flexibility*, students would pass their card to a neighbor, and who were asked to count the number of ideas listed, or the number of categorically different ideas listed. For *originality*, students were asked to volunteer their ideas as being especially original, and the top several were put to a class vote. The award was variable and not known in advance to the students – the smallest bill in the wallet of the instructor, ranging from $1-$20.

Results

Demographics: This study encompassed 104 students in two semesters. The intervention group included 56 students, of whom 31 were female (55%) and 4 were from underrepresented groups in STEM (7%). The control group included 48 students, of whom 29 were female (60%), and 2 were from underrepresented groups (4%).

Creativity increased over the course of the semester: Our data was accepted to be normally distributed by Kolmogorov-Smirnov test. There were no statistically significant beginning-of-semester differences by any assessment between the control and intervention sections by unpaired t-test. Further, the overall scores for end-of-course evaluations did not differ between the semesters ($p=0.46$; effect size, Cohen’s $d=0.02$).

Regardless of course section, control or intervention, there was a significant improvement by the end of the semester in the *fluency*, *flexibility*, and *originality* aspects of *creativity* (Table 1). These changes reflect those seen by us in a first-year engineering course with an authentic design experience [1], though the changes seen in the skills-based course presented here were considerably larger in effect size.

Aspect	Section	Day 1	Final	Change	p	d
fluency	Control	6.6 ± 0.4	9.0 ± 0.8	+37%	0.003	0.84
	Intervention	5.9 ± 0.4	8.2 ± 0.4	+39%	<0.001	0.82
flexibility	Control	4.9 ± 0.3	6.5 ± 0.4	+32%	<0.001	0.85
	Intervention	4.4 ± 0.3	6.25 ± 0.4	+42%	<0.001	0.91
originality	Control	2.9 ± 0.2	3.3 ± 0.2	+16%	0.07	0.30
	Intervention	2.6 ± 0.2	3.3 ± 0.2	+24%	0.008	0.44

Table 1: Creativity increases over the course of the semester for both the control (shaded) and intervention groups.

Improvements in *creativity* were paralleled by improvements in *self-efficacy*: As in our past work, we here found significant semester-long gains in most aspects of *engineering design self-efficacy*. Effect-sizes in the several domains of this construct, comparing the final to the initial day of class, are provided in Table 2. While gains are not universal, they are broad and similar between the two groups. The largest effect size is in activity of communication.

Scores from the nine activities for each aspect of self-efficacy were summed to create a generalized score. As one would expect based on the scores in Table 2, there were generalized increases in the *ability*, *motivation*, and *apprehension* aspects of *self-efficacy* by the end of the semester, but no change in *success*. Each of these increases were of large effect size. As noted by the sign on Cohen's d value, *apprehension* increased. This was unexpected, and is addressed in the discussion.

	Ability	*Success*	*Motivated*	*Apprehen.*
Design	1.10	0.04	0.50	0.50
Need	0.84	0.18	0.50	0.50
Research	0.05	0.21	0.13	0.13
Solutions	0.78	0.09	0.28	0.28
Select	0.37	-0.20	0.00	0.00
Prototype	1.26	-0.13	0.79	0.79
Test	1.04	-0.27	0.25	0.25
Commun.	3.16	0.13	0.75	0.75
Iterate	1.04	0.25	0.98	0.98

	Ability	*Success*	*Motivated*	*Apprehen.*
Design	1.05	0.04	0.66	0.66
Need	0.90	-0.11	0.33	0.33
Research	0.61	0.10	0.11	0.11
Solutions	1.00	0.16	0.67	0.67
Select	0.26	0.00	-0.11	-0.11
Prototype	1.38	-0.09	0.60	0.60
Test	1.58	0.13	0.66	0.66
Commun.	2.99	0.03	0.47	0.47
Iterate	1.03	0.17	0.92	0.92

Table 2: Self-efficacy increases over the course of the semester for both the control (left) and the intervention (right) groups. The values indicate Cohen's d value for effect size. Shaded cells (green or gold) indicate $p<0.05$.

Creative thinking did not improve with overt training in creativity: While all three measured aspects of *creativity* increased significantly over the course of the semester, there was no difference between the control and intervention groups. There were trends toward the intervention group having greater increases in *fluency* (6% over control), *flexibility* (30% over control), and *originality* (50% over control), but these differences were of very small effect size ($d = 0.05$, 0.16, and 0.17 respectively), and were not statistically significant by unpaired t-test.

This finding was paralleled by *self-efficacy* gains between the two groups. In only three specific aspects did we see significant gains of the intervention group over the control group. These were in *success* in conducting engineering design ($d=0.50$, $p=0.046$), *success* in prototyping ($d=0.54$, p=0.04), and *success* in testing a design (d=0.66, p=0.017). It is interesting that these gains were in the *success* aspect of *engineering design self-efficacy*, since that is the only aspect of this construct not to show generalized increases over the course of the semester.

Discussion

While a skills-based course in design promotes creativity, overt training in creativity fails to elicit an additional improvement. The former is perhaps expected. Students in this design course invariably engage in the Osborn-Parnes process to one extent or another – that is, rounds of brainstorming to improve the creative process [13, p. 465]. Torrance noted that the Osborn-Parnes process may be one of the only effective ways to foster *creativity* in children [14]. Studies have also suggested that the Osborn-Parnes process improves *self-efficacy* [15], [16]. Thus, brainstorming may explain the semester-long gains we observed in *creativity* and possibly contributed to their gains in *engineering design self-efficacy*. As noted in the introduction, it is thought also that *self-efficacy* may promote *creativity* [6]. Indeed, as non-cognitive and pseudo-cognitive *constructs*, they may be impossible to fully separate.

The failure of overt practice in creative thinking to elicit additional gains in *creativity* is somewhat surprising. After all, the practices in which the students were engaged daily were rewarded, and were very similar to the assessments themselves. One can think of this as "teaching to the test." Three possible explanations stand out for this lack of effect. First, it could be that the students lacked the same financial motivation during the assessment that they had during the daily exercises, thus skewing the results. Second, the structure of the course could preclude additional cognitive or non-cognitive gains; indeed, the semester is quite full. However, the course evaluations do not reveal any stress about overwhelming content, other than that the final project feels compressed in time.

We favor a third explanation, that the Osborn-Parnes process saturated the students' single-semester learning gains in creative thinking, or that the learning gains from Osborn-Parnes simply overwhelmed smaller learning gains from overt training. Indeed, the effect sizes for semester-long gains in creativity were quite large, and perhaps leave little room for improvement. We could very well see gains in creative thinking if overt practice, such as that used here, were incorporated into non-design courses.

One might assume such gains to be due to educational experiences outside of the course in question. However, our second-year curriculum is structured such that any BME course can be taken in either the fall or the spring. As a result, the students are taking a relatively random assortment of classes in any given semester. The design course reported here is the only universal factor.

The increase in the *apprehension* aspect of *self-efficacy* was unexpected, and stands in contrast to our previous findings with first-year engineering students [1]. One would assume students' concerns about engaging in design to decrease after receiving a semester of training on engineering design. We hypothesize that the increase in apprehension may have been due to the intensive, closed-ended design project at the end of the semester. The project proved to be unexpectedly challenging and unexpectedly stressful for students, as remarked upon in course evaluations. Further, a culminating demonstration of the device by the team was required at the final exam, meaning that for many students the final assessment was taken just prior to the formal completion of the project.

To summarize, an engineering design course rich in development of skills and capped off by a closed-ended project elicits significant gains in all aspects of creativity, and many aspects of engineering design self-efficacy. Additional training in creativity does little to improve over what a design class already delivers.

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