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Changes in Affective Capacities of CAD Students Engaged in an Engineering Design Project

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As one of Quinnipiac University's Founding Faculty members, John Reap helped shape, foster and guide its undergraduate focused engineering school. Founded in 2012 with civil, industrial, mechanical and software engineering programs, the school grew from two faculty and ˜30 students to 17 faculty and over 400 students, adding computer science and cyber security programs along the way.

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Abstract

Success in open-ended design activities requires a desire to succeed and a belief in one's ability to succeed when faced with ambiguously defined problems. Engineering design courses ideally develop these affective capacities as well as technical skills. Multiple approaches to enhancing them in a design course exist, and this study evaluates the use of entrepreneurial design projects in a first computer aided design (CAD) course. The study quantifies changes in affective capacities in terms of Need for Achievement (nAch), Generalized Self-Efficacy (GSE), and Tolerance for Ambiguity (ToA). Surveys deployed at the start and conclusion of the CAD course provide the data needed to evaluate these changes. A paired sample t-test for those who responded to both entry and exit surveys (N=14) shows an absence of significant change for any of the measured affective capacities. However, a small number of individual students exhibited noteworthy, though not statistically significant, changes for one or more of the three measures. This outcome points to the value of conducting larger studies or of augmenting quantitative methods with qualitative ones in the future. Examination of individual questions in the survey instrument hint at improvements in the ability to view problems holistically, consider others' thinking and manage anxiety. Changes in specific GSE and nAch questions may reflect a realization of the challenges presented by the entrepreneurship clients' more realistic design problems and by understanding the thinking of others. Factors such as age, presence of a close family member with engineering experience, and prior work in engineering significantly affect one or more regressions of nAch, GSE, and ToA values. Lower Initial ($p = 0.026$) and Final nAch ($p = 0.032$) appear for students with prior work in engineering. Those with a close family member working in engineering exhibit higher Initial ($p = 0.004$) and Final ($p = 0.002$) GSE, and a quite modest increase in ToA ($p = 0.036$) correlates with age. Though the small sample size and focus on a single collegiate population limit one's ability to draw conclusions, these interesting data point to hypotheses that future studies can further interrogate.

Keywords

Achievement motivation, Self-efficacy, Ambiguity, Pedagogy, Computer aided design

Introduction

In addition to technical acumen, success in open-ended design requires strengths in affective traits that include a desire to succeed and a belief in one's ability to succeed when faced with ambiguously defined problems. Engineering design courses ideally develop both technical and affective capacities. Effective means of developing technical skills exist; they form the core of traditional engineering curriculums. Development of affective capacities traditionally received less attention despite indications of their importance. Stolk and Harari, for instance, identified a need for further investigation of connections between engineering college students' motivation and cognitive development [1]. Introduction of entrepreneurship in engineering design offers one approach that may enhance these traits. Prior research conducted in an introductory engineering course suggests that interaction with a "real" customer, other than the course instructor, enhances students' perceived capacity to perform design tasks such as identification of customer requirements [2]. Substantial interaction between mechanical engineering and entrepreneurship students in a senior level capstone course resulted in noteworthy improvements in final project quality [3].

When entrepreneurship is present, as it is in this study, a recent literature review identified a need for more studies that measure its educational impacts [4]. This is not a new conclusion. Immersion in a process, such as the one conducted in this study, or even a simulation allows children to learn extensive amounts of information in short periods of time [5]. However, few pedagogical impact investigations interrogate more than direct, overall academic achievement, even with one of the most studied constructs, achievement motivation [6], and there are calls for continued exploration into such constructs' impacts on the components that lead to academic achievement [7].

Evaluating an entrepreneurship focused design activity's influence on the affective capacities of engineering students serves as this study's goal. The evaluated approach centers students' design experiences around interactions with entrepreneurship students. Forming a consultant-client relationship, mechanical engineering students develop product ideas initially pitched by entrepreneurship students. A sophomore level mechanical engineering computer aided design (CAD) course provides the context for the engineering-entrepreneurship interaction. The work measures changes in students' affective capacities in terms of Need for Achievement (nAch), Generalized Self-Efficacy (GSE), and Tolerance for Ambiguity (ToA).

Literature & Background

An extensive body of literature exists for ToA, GSE and nAch. It defines the terms and provides constructs for measuring them. Prior work on these affective constructs also imparts an appreciation of their applicability to the domains of entrepreneurship and engineering education. Tomczyk previously reviewed this literature from an entrepreneurial perspective [8]. This section revisits each measure and adds a connection to the engineering education context relevant to this work.

Situations with complexity, novelty or insolubility create ambiguity, and Budner formalized the concept of tolerance for ambiguity as a studied personality trait [9]. Ambiguous or uncertain situations lack sufficient data to structure them [10]. Some seek unstructured situations to face the challenge of overcoming ambiguity while others view uncertainty as a stressful, even threatening, state [11]. A greater willingness to take a risk when faced with a decision is a sign of high tolerance [10]. In the engineering context, freshmen engineering students often exhibit discomfort with the ambiguity of open ended design problems [12], and those with higher tolerance appear to fare better on measures of collective efficacy, team satisfaction and conflict resolution [13]. ToA also correlates with design creativity and selection of concepts [14].

Bandura defines self-efficacy, the second concept, as task-specific self-confidence [15]. Research shows that those who believe that they possess the requisite skills and capabilities to pursue a discipline are more likely to do so [16]. Generalized self-efficacy broadens this confidence to a wide variety of tasks [17]. Low and high general self-efficacy individuals think and behave differently[18], with high GSE individuals more likely to succeed at a range of tasks

[19] [20] [21]. In engineering classrooms, higher GSE correlates with better performance in engineering projects [22].

Achievement motivation, also called the need for achievement and abbreviated as nAch, has been studied extensively in academic achievement literature [7]. In 1953, McClelland and colleagues provided the primary definition of need for achievement [23]. Persons exhibiting nAch possess four main behavioral traits: taking responsibility for finding solutions to problems, taking calculated risks, setting goals for achievement, and desiring concrete feedback on performance [24]. Persons with high achievement motivation likely take practical, detailed steps leading to realistic, achievable goals [25]. Being high in nAch also has implications for perceptions of material rewards, as such things do not satisfy their internal needs [26]. Individuals with high nAch satisfy status needs with achievements [26], may take pleasure from generating resources [27], or may simply desire to improve efficiency, solve problems, or master tasks [28]. One of the commonalities is that achievement motivation is holistically applied to a person's work and life; it is not confined to specific areas [29]. A neural study supports this holistic perspective with data indicating that the same areas of the brain activate when individuals report motivation to learn or earn a monetary reward [30]. Given the commonality and presence of a physiological foundation for that commonality, one expects achievement motivation to influence engineering students' performance.

Method

This section describes the entrepreneurial intervention in a sophomore level CAD course and the survey tool used to gather affective capacity data. The survey tool contains questions meant to gage Tolerance for Ambiguity (ToA), Generalized Self-Efficacy (GSE), and Need for Achievement (nAch).

Entrepreneurial Design Intervention

Faculty from the mechanical engineering and entrepreneurship programs initiated the intervention by actively recruiting entrepreneurially minded students from non-engineering majors using email messages and in-person appeals. Both recruitment methods target business course sections and entrepreneurship clubs likely to contain interested parties. The entrepreneurial students receive the engineering students' design work (engineering drawings, 3D CAD models, etc.) at the close of the semester. Prior to commencing their projects and at the close of the projects, engineering students working on entrepreneurial projects receive invitations to take the affective capacities survey. Table 1 summarizes the sequence of design project and research data collection events.

Table 1: Sequence of Events for Entrepreneurially Driven Projects

Project Activity	**Research Data Event**
Recruitment of entrepreneurial students	Initial affective capacity survey offered to ME students
Entrepreneurs pitch project ideas to ME students	
ME student teams form around entrepreneurship projects based on preference	
ME students generate milestone documents during the semester (Requirements List and Problem Statement, conceptual design, embodiment and detail design with CAD)	
Presentation of final design to course and entrepreneurship clients	Final affective capacities survey offered to ME students

Executed in the fall of 2019, the intervention began with recruitment of six student "clients" majoring in entrepreneurship or involved in the entrepreneurship club. These clients pitched their ideas to engineering students enrolled in the CAD course during an event facilitating brief interactions with both sets of students. Small groups (3-4) of engineering students rotated among potential clients, hearing and responding to the clients' pitches. Some clients openly expressed a desire to recruit engineering students to their entrepreneurial teams for purposes beyond the bounds of the CAD course project. Both the entrepreneurial student clients and engineering student "consultants" rated each other, and the ratings provided a means of guiding team formation for each project. By exposing the engineering students to motivated clients offering projects with potential benefits beyond a course grade and by giving them a hand in selection of their projects, the researchers believed that the engineering students desire to achieve might be increased.

After team formation, the engineering and entrepreneurial students interacted to generate a task clarification document containing a concise problem statement and list of requirements for the project. The comprehensive requirements list structure found in the work of Pahl and Beitz served as a template [31]. Preparation of these documents required the engineering students to grapple with the entrepreneur's idea and deal with the technical ambiguity associated with transforming that idea into specifications capable of guiding the next phase of design.

Conceptual design followed task clarification. Each student team developed and selected a concept meant to meet the developed specification. The teams presented this effort in the form of a conceptual design report. This demanded application of creative and technical skills. The researchers believed that facing such a challenge could develop students' belief in their ability to execute engineering tasks. In addition, teams often found that a degree of iteration between task clarification and conceptual design occurred at this stage, and they needed to deal with the expectations of their entrepreneurial clients. The researchers hoped that this expected iterative activity would promote each student's ability to manage the ambiguity of early stage design.

With a satisfactory concept in hand, the engineering teams proceeded to embody their designs and document them using engineering drawings. This occurred in the last quarter of the course at a time when students had built CAD skills by completing the course's non-project exercises. It was hoped that practicing these skills would increase the engineering students' confidence in applying them. The final development of the project also transpired with the knowledge that the teams would present their work to their clients, and by this point in the semester, some of the engineering students had become part of the clients' entrepreneurial teams. It was hoped that such close interaction with the clients would raise student desire to achieve.

Affective Capacities Survey

The affective capacities survey employed in this study is the same instrument originally used in Tomczyk's doctoral work [8] (See Table 2-Table 4). His survey measures tolerance for ambiguity (ToA), generalized self-efficacy (GSE), and need for achievement (nAch) using prompts requiring Likert scale responses that range from 1 (Strongly Disagree) to 5 (Strongly Agree). His instrument combines elements from multiple previously developed and verified surveys for the stated affective capacities. Tomczyk's survey uses the original 20 item Rydell and Rosen scale [32] for tolerance for ambiguity (Cronbach's $\alpha = 0.78$), in which a higher aggregate score indicates a desire for unambiguous situations. For measuring generalized self-efficacy, it uses Woodruff's and Cashman's 12 item instrument that groups self-efficacy into three components: initiative, effort, and persistence [33], but following the approach of Bosscher and Smit [34], it combines all three into one higher-level component of generalized self-efficacy (GSE) (Cronbach's $\alpha = 0.69$). Higher aggregate scores indicate increased generalized self-efficacy. The affective capacities survey measures the need for achievement using a 15-item tool that combines prompts from multiple previously developed instruments known for their high internal reliability [19] and capacity to account for all nAch components (taking responsibility for finding solutions to problems, taking calculated risks, setting goals for achievement, and desiring concrete feedback on performance) [35]. A higher nAch score points to a greater need to achieve.

Table 2: Tolerance for Ambiguity (ToA) Prompts

A problem has little attraction for me if I don't think it has a solution.
I am just a little uncomfortable with people unless I feel that I can understand their behavior.
There's a right way and a wrong way to do almost everything.
I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner.
The way to understand complex problems is to be concerned with their larger aspects instead of breaking them into smaller pieces.
I get pretty anxious when I'm in a social situation over which I have no control.
Practically every problem has a solution.
It bothers me when I am unable to follow another person's train of thought.
I have always felt that there is a clear difference between right and wrong.
It bothers me when I don't know how other people react to me.
Nothing gets accomplished in this world unless you stick to some basic rules.
Vague and impressionistic pictures really have little appeal for me.
Before an examination, I feel much less anxious if I know how many questions there will be.
Sometimes I rather enjoy going against the rules and doing things I'm not supposed to do.
I like to fool around with new ideas, even if they turn out later to be a total waste of time.
Perfect balance is the essence of all good composition.
If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or X-ray specialist.
If I were a scientist, I might become frustrated because my work would never be completed (science will always make new discoveries).
I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer.
The best part of working a jigsaw puzzle is putting in that last piece.

Table 3: Generalized Self-Efficacy (GSE) Prompts

If something looks too complicated, I will not even bother to try it.
I avoid trying to learn new things when they look too difficult.
When trying something new, I soon give up if I am not initially successful.
When I make plans, I am certain I can make them work.
If I can't do a job the first time, I keep trying until I can.
When I have something unpleasant to do, I stick to it until I finish it.
When I decide to do something, I go right to work on it.
Failure just makes me try harder.
When I set important goals for myself, I rarely achieve them.
I do not seem to be capable of dealing with most problems that come up in my life.
When unexpected problems occur, I don't handle them very well.
I feel insecure about my ability to do things.

Table 4: Need for Achievement (nAch) Prompts

I get my biggest thrills when my work is among the best there is.
I never put important matters off until a more convenient time.
I believe it is important to analyze your own weaknesses in your school work.
I often sacrifice personal comfort in order to take advantage of opportunities.
I do every job as thoroughly as possible.
I believe that to be successful in life a person must spend time planning the future.
I believe that one key to success is to not procrastinate.
I get a sense of pride when I do a good job on my school projects.
I feel proud when I look at the results I have achieved in my activities.
I believe it is more important to think about future possibilities than past accomplishments.
I make it a point to do something significant and meaningful every day.
I feel depressed when I don't accomplish any meaningful work.
I get a sense of accomplishment from the pursuit of my goals.
I often take calculated risks.
I like to receive feedback on my work as soon as possible.

Results

Table 5: Summations of Survey Scores and Differences for ToA, GSE and nAch

	ToA			GSE			nAch		
Student	Before	After	Change	Before	After	Change	Before	After	Change
1	59	58	-1	35	34	-1	57	54	-3
2	62	63	1	35	36	1	64	56	-8
3	72	72	0	38	39	1	64	65	1
4	63	58	-5	31	34	3	53	45	-8
5	60	58	-2	32	31	-1	56	55	-1
6	56	70	14	33	34	1	54	60	6
7	59	70	11	28	31	3	54	55	1
8	62	62	0	35	35	0	58	58	0
9	61	68	7	32	32	0	56	57	1
10	73	62	-11	29	30	1	62	57	-5
11	64	68	4	39	36	-3	53	54	1
12	77	71	-6	36	41	5	62	66	4
13	58	58	0	32	30	-2	64	62	-2
14	59	57	-2	26	28	2	58	55	-3

Table 6: Summations for Noteworthy Individual Questions (N=14)

	Prompt	Row Sum
ToA	The way to understand complex problems is to be concerned with their larger aspects instead of breaking them into smaller pieces.	6
	I get pretty anxious when I'm in a social situation over which I have no control.	-5
	It bothers me when I am unable to follow another person's train of thought.	7
	I like to fool around with new ideas, even if they turn out later to be a total waste of time.	-4
	If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or X-ray specialist.	5
	I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer.	4
GSE	I avoid trying to learn new things when they look too difficult.	4
	When trying something new, I soon give up if I am not initially successful.	4
	When I make plans, I am certain I can make them work.	-6
	Failure just makes me try harder.	4
nAch	I feel proud when I look at the results I have achieved in my activities.	-5
	I make it a point to do something significant and meaningful every day.	-5

Table 7: Paired Sample t-tests for ToA, GSE and nAch

	Paired Differences					**Significance**	
Initial -Final	*Mean*	*Std. Dev.*	*Std. Error Mean*	*t*	*Df*	*1-sided p*	*2-sided p*
ToA	-0.714	6.603	1.765	-.405	13	0.346	0.692
GSE	-0.714	2.128	0.569	-1.256	13	0.116	0.231
nAch	1.143	4.055	1.084	1.055	13	0.155	0.311

Table 8: Multivariate Regression for Age of Students

Dependent Variable	Total Mean	Std. Dev.	Sig.
Initial ToA Sum	63.21	6.290	0.256
Change in ToA	0.71	6.603	0.036

Table 9: Multivariate Regression for Close Family Member Working in Engineering and GSE

Dependent Variable	Close Family Works in Engineering	N	Mean	Std. Dev.	sig.
Initial GSE Sum	No	10	31.30	2.908	0.004
	Yes	4	37.00	1.826	
	Total	14	32.93	3.710	
Final GSE Sum	No	10	32.00	2.449	0.002
	Yes	4	37.75	2.754	
	Total	14	33.64	3.629	

Table 10: Multivariate Regression for Prior Work Experience in Engineering and nAch

Dependent Variable	Prior Work in Engineering	N	Mean	Std. Dev.	sig.
Initial nAch Sum	No	9	60.00	4.000	0.026
	Yes	5	55.00	2.345	
	Total	14	58.21	4.209	
Final nAch Sum	No	9	59.22	4.236	0.032
	Yes	5	53.20	4.868	
	Total	14	57.07	5.225	

Discussion

Paired sample t-tests for students who responded to both initial and final surveys (N = 14) reveal that ToA, GSE and nAch remained statistically unchanged for the group (See Table 7). Both 1-sided and 2-sided p values fell well above 0.05 for all three measures. The absence of a significant change in the group's affective dispositions suggests one of two possibilities. Either the single semester design project promoting interaction between mechanical engineering and entrepreneurship students failed to change the affect of the group, or the study's available sample size proved too small to give the statistical power needed to detect differences.

Examination of data for individual students reveals nine cases for seven different students in which the change from initial to final surveys exceeded 10% for at least one metric (See Table 5). For instance, Students 6, 7, 9 and 10 experienced changes for ToA in excess of 10%, with the first three experiencing sharp increases and the last showing a substantial decrease. Students 6 and 7 also registered similar increases in nAch and GSE, respectively. Students 2 and 4 experienced >10% declines in nAch, but Student 12 shows a noteworthy increase in GSE. These spikes might be part of the dataset's background noise. Alternatively, they suggest a trend that may prove detectable by a larger study. They certainly beg a few direct questions. Why, for example, did Student 6's ToA rise by 25%? A qualitative study might have yielded insight into this comparatively large change, and future work in this area could benefit from such a component.

Individual questions in the survey instruments also hint at potentially noteworthy effects. Summing responses from all students for individual questions highlights 12 of the 47 questions in the survey instruments as registering outsized changes (See Table 6). For noteworthy questions in the ToA, one sees an increase in the willingness to view problems holistically and understand the thinking of others. Anxiety when faced with uncontrolled situations decreases, and one sees an increase in the acceptance of the uncertainties of practice. These results hint at increased capacity to engage in open-ended problems addressed in a team environment. Two of the questions in this section also point to a decrease in a willingness to spend time on apparently fruitless ideas. These later two outcomes may reflect a recognition of time constraints. Noteworthy changes in specific questions in the GSE section paint a nuanced picture of student attitudes. Three of the questions show a decrease in students' desire to face new challenges and in their belief in successfully completing tasks. On the other hand, one question shows an increase in a desire to try harder when faced with failure. Questions from the nAch section show a decrease in students' pride in their results and desire to achieve meaningful results during a particular day. Taken together, these changes in specific GSE and nAch questions may reflect a realization of the challenges of the more realistic design problems presented by the entrepreneurship clients. The Dunning-Kruger Effect might, therefore, explain the drop in GSE and nAch. Students with lower expertise and experience encountered more realistic design problems for the first time, and this recalibrated their perception of the associated challenges. They may also indicate that the presented design problems proved too challenging for sophomore level or that additional support is needed to engage in such projects. However, one must remember that a claim of statistical significance for the row sums is not made. Rather, these interesting data point to hypotheses that further studies can interrogate.

Regressions for some of the sample's demographic factors proved significant. The quite modest mean change in ToA (0.71) proved significant ($p = 0.036$) for student age (See **Table** 8). Larger and more interesting significant differences appear for GSE and nAch when considering the presence of a close family member in engineering or past experience working in an engineering context. A close family member in engineering correlates with higher Initial GSE ($p = 0.004$) and Final GSE ($p = 0.002$) (See Table **9**). The success of a family member appears to raise a student's belief in his own success when faced with the type of problems presented by this design project. Interestingly, experience provided by work in engineering lowered both Initial nAch ($p = 0.026$) and Final nAch ($p = 0.032$) (See Table 10).

Closure

The aggregate affective capacities of students in this study appear unaltered. For this sample, measures of Need for Achievement (nAch), Generalized Self-Efficacy (GSE), and Tolerance for Ambiguity (ToA) remained statistically unchanged between the start and conclusion of the described entrepreneurial engineering design experience. Yet, some of those measures show substantial (>10%) changes for some students in the sample. Examination of aggregate data for individual questions points to noteworthy, though not statistically evaluated, patterns.

The study's results generate multiple directions for future investigation. The difference between the aggregate outcome and some of the individual data points argues in favor of increasing sample size to increase statistical power in future surveys. A qualitative element of any following study might reveal reasons for the spikes in affective measures for a small number of students. Most intriguingly, patterns in aggregate questions suggest hypotheses worth further investigation. ToA patterns potentially hint at a building of capacity to engage in open ended problem solving within a team environment, and aggregate changes in select GSE and nAch questions may reflect a realization of the challenges of the more realistic design problems presented by the entrepreneurship clients.

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