Building Strong Academic Mindsets Focusing on Grit, Mastery Orientation, Belonging, and Self-Efficacy via an Effort Contingent Learning Environment in a Senior Engineering Capstone Design Course

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With the expectation that engineering students ought to be prepared to adapt to a continuously evolving workplace environment to solve the complex problems of the future, engineering educators ought to also adapt and provide innovative learning environments that support not only technical agility, but also psychological agility to support the development of our students. Capstone design serves as an ideal context to support engineering students with this preparation. This paper describes how a senior capstone design course was transformed not in content, but in the classroom values/culture, reward structures, and the learning environment to encourage mastery learning though effort contingencies, grit and perseverance, collaboration, and empowerment. Designed as a pre-test post-test control group design, a set of psychological constructs (grit, sense of belonging, achievement goal orientation, self-efficacy, impulsivity) were administered to a treatment group and a control group to investigate effects of the educational innovations. Effect sizes reveal moderate to high practical significance comparing the treatment and control groups.

Keywords: capstone design, goal orientation, grit, effort contingent learning, belonging

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Introduction

What if we as faculty could train our students (like coaches train athletes) to not give up, to persevere, to perform at the highest levels, to not lose sight of the end goal, to stay engaged, to belong, and to excel? What if we could shift educational priorities to promote psychological preparation alongside academic preparation?

With the rapid pace of technological change, the future engineer is not only expected to offer technical ingenuity but also to *adapt to a continuously evolving environment* to solve the *complex problems of the future*. The success of the U.S. in global competitiveness is tied directly to the complex problem solving ability of its technical workforce. How can we prepare students to face the complex problems that society requires of engineers to solve? Capstone design and senior design courses are an ideal context to help prepare students for the workforce.

Being an engineering student can be tough and usually means facing greater academic challenges. The classes are often harder, the programs are often longer, the grades are often lower, and the commitment and self-discipline required are often greater. To give students the best chance of succeeding in the real world, pedagogical innovations like problem based learning, project based learning, inquiry based learning, and other active learning pedagogies have been implemented for preparing engineering students to face complex problem solving. While often successful, most of these educational strategies have focused on academic preparedness, while few have sought to prepare students mentally or psychologically. An inability to cope with the psychological demands of engineering contributes significantly to demotivation and attrition (both in the classroom and potentially in the workplace). Compelling evidence from psychological and educational research suggests that a *proactive approach*, rather than the more common *reactive* approach of targeting "at risk" students (who may feel further alienated for receiving extra attention), could significantly increase students' intrinsic motivation and engagement, leading not only to more grit and persistence, but to better academic performance as well[1].

Acknowledging both academic and psychological demands of complex problem solving, this paper presents the impacts of reframing a senior level capstone design course sequence (fall and spring) as effort contingent learning environments (ECLE). An

ECLE was established by reframing what is valued and what is rewarded in these courses. Students in these courses were rewarded for quality effort, evidence of competency learning, perseverance, active participation in class activities, peer teaching efforts, etc. **The guiding research question was "what are the impacts of an effort contingent learning environment during capstone design?"**

Relevant Literature

A burgeoning educational movement has been exploring the impact of non-cognitive and psychological factors (as opposed to cognitive and academic factors) on student success at all levels. The importance of psychological preparation prior to a challenging task or journey, as well as staying attuned to one's own psychological state during such a task, has been demonstrated in many contexts, perhaps most notably in competitive athletics and the military. Effective psychological preparedness activities often lead to greater resilience and the ability to maintain motivation in the face of uncertainty or self-doubt. In theory, equipping engineering students with such capabilities leads to increased motivation, persistence, and retention.

One of the most important psychological constructs for this effort is *grit*, a non-cognitive trait encompassing perseverance and passion to pursue goals with sustained effort over time[2]. Grit has been investigated as an explanation for why individuals of similar intelligence succeed in different numbers of objective accomplishments throughout their lives. Grit, which is related to conscientiousness, perseverance, tenacity, and the need for achievement, emphasizes long-term stamina for consistent goals even in the absence of immediate feedback or explicit rewards. Psychological interventions designed to promote grit within engineering student populations are rare. What does it mean to be a gritty engineering student? Prototypically, this is a student who is self-disciplined, who believes in their ability to succeed in engineering (self-efficacy), who can manage their own anxiety, who exhibits prosocial behavior and manages social conflict, who is not afraid of failure, who possesses the self-control required to inhibit impulses and delay gratification when necessary, who is flexible and adapts well to new learning environments, who feels a sense of connectedness and belonging within their program, and whose professional identity strengthens over time. In a sense, grit is the embodiment of numerous other psychological skills and qualities. Some of the most relevant psychological theories (**Table 1**) guiding us in designing environments to promote psychological preparedness.

Table 1: Relevant psychological theories.

Achievement Goal Theory (AGT)	
A motivational theory, AGT posits that achievement goals may be pursued for reasons that are either intrinsic (mastery-oriented) or extrinsic (performance-oriented).	
Constructs	**Mastery vs. Performance Goal Orientation –** Mastery oriented goals tend to promote long-term, high-quality learning, and college students with a mastery orientation are typically more engaged in class and receive higher grades compared to students with performance goals[3].
	Approach vs. Avoidance Goal Orientation – Approach goals tend to contribute positively to intrinsic motivation whereas avoidance goals do not[4].
Self-Determination Theory (SDT)	
SDT is a theory of motivation concerned with supporting individuals' natural tendencies to behave in effective and healthy ways. Fulfillment of the three fundamental elements of SDT has been empirically linked to personal and academic success[5].	
Constructs	**Competence** is the belief that one can influence important outcomes.
	Relatedness is the experience of having satisfying and supportive social relationships.
	Autonomy is the experience of acting with a sense of choice, volition, and self-determination.
Social Identity Theory (SIT)	
Groups give individuals a sense of social identity: a sense of belonging to the social world[6]. Level of commitment determines how group characteristics, norms, and outcomes influence the perceptual, affective, and behavioral responses of individuals belonging to that group[7].	
Constructs	**In-Group Cooperation–** In-group cooperation speaks to collective action and goal pursuit. Willingness to work and bond with others for a common purpose is important to identifying with, and benefitting from, a social group.
	Sense of Belonging – Belonging refers to a need to feel closeness to, and acceptance by, other people, both in dyadic and group contexts. When choosing to leave a group, people often report feelings of improper "fit" or a lack of belonging.

The Context: Transforming the Classroom Environment and the Reward Structures

The context for this study was a senior design course sequence (treatment group), which comprises of a classroom component as well as a capstone project experience[8]. The following attributes describe how the classroom environment was transformed.

Establishing the Class Culture via Shared and Student-Derived Values and Behaviors – The first day of class began with an activity designed to elicit students' beliefs of workplace expectations (peer to peer expectation, supervisor expectations for employees, employee expectations of supervisor, workplace environment, etc.). What derived from this activity became the expectations for the class. The classroom was envisioned as a workplace environment with a derived set of values and expected behaviors. This activity set the culture and tone for the course and from an SDT point-of-view enabled autonomy, relatedness, and competence.

Aligning Effort Contingent Learning and Rewards – Research shows that evaluation practices focused on effort rather than ability trigger mastery learning strategies and better knowledge retention[9]. In the classroom, extrinsic rewards are often given with good intentions, but they can have detrimental effects when the rewards are perceived as bribes or controlling[10]. When rewards are made contingent on student effort, rewards can enhance achievement-directed behavior and even lead to an increase of task persistence. The treatment group/course was transformed into a classroom where effort was the emphasis to produce quality work and perform at high standards. The grading rubric that was developed and used aligned with this focus on effort and facilitated the evaluation of student work from the point of view of quality of effort. Further, to encourage quality effort and mastery learning, students were allowed to resubmit graded work for a second time in an attempt for them to show deeper understanding and quality effort.

Empowering Students with Autonomy, Self-pacing, and Inductive Teaching Methods – Strategies that allow students to set their own pace with short-term goals or assignment leads to intrinsic motivation. Inductive teaching methods enable students to more effectively solve problems and self-manage goals and their learning. In the treatment course, a non-traditional pedagogical model was implemented. Interteaching[11], which is new and has been used in psychology but almost non-existent in STEM education, emphasizes independent learning. Students complete a preparation guide before class that includes reading material and questions. At the beginning of class, the professor clarifies difficult concepts emerging from the previous class. Much of class time is focused on students working/teaching in pairs or small groups. Professors and teaching assistants are available for questions and discussion. At the end of class, students complete a record sheet identifying challenges. Professors use this feedback in preparing for the next lecture.

Using Proactive, Team based Motivational Strategies to Support Capstone Projects - Highly valued in competitive athletics, the military, and other fields where qualities such as resilience and persistence are essential to success, team-based strategies are effective in building in-group cooperation. Team cohesion, authentic collaboration, and collective efficacy were frequently discussed in the course to motivate completion of capstone projects. Discussions and activities targeting team performance and "collective efficacy" helped to establish a sense of common experience and purpose in collaborative capstone projects.

Methodology

This study was designed as a pre-test post-test control group design, which is common in educational research settings to investigate effects in educational innovations. The pre-test and post-test were exactly the same and were respectively administered a few of days prior to the start of the semester and during the last week of the semester. The surveys included the following measures:

(1) Short Grit Scale (Grit-S): A short version of the Grit Scale, Grit-S[12], was used to measure *consistency of interest* and *perseverance of effort.*

(2) Achievement Goal Questionnaire (AGQ): Grounded in achievement goal theory (see above), the subscales of AGQ are *mastery approach*, *performance approach*, *mastery avoidance*, *performance avoidance,* and *work avoidance*.

(3) Dickman Dysfunctional Impulsivity Scale: Defined as "the tendency to act with less forethought than most people of equal ability when this tendency is a source of difficulty,[13]" dysfunctional impulsivity was assessed in the context of engineering problem solving.

(4) Sense of Belonging: This subscale was adapted from the perceived cohesion scale[14] and theory to measure sense of "fit" and "belonging."

(5) Self-Efficacy: Derived from self-efficacy literature[15], the subscale included was *self-efficacy for academic achievement*.

Participants in this study included senior engineering students in two sections of the same course that shared the same syllabus and content coverage (Table 2). One section served as the control group and the other as the treatment group. There were 30 students in the control group/section and 31 in the treatment group/section. Section placement was based on keeping capstone teams in the same section. The demographics were similar in both groups with about 20% female students.

Table 2: Treatment and control groups.

Group	PRE Survey	POST Survey
Treatment	**N=28 (90% response rate)**	**N=23 (74% response rate)**
Control	**N=27 (90% response rate)**	**N=20 (67% response rate)**

Data analysis involved effect sizes, which are quantitative measures of the strength of a phenomenon and a simple way of quantifying the difference between two groups, which has many advantages over the use of tests of statistical significance alone. Effect size places an emphasis on the size of the difference rather than confounding this with sample size. In pre-test post-test control group designs, it has been suggested that effect size should be based on the mean pre-post change in the treatment group minus the mean pre-post change in the control group, divided by the pooled pretest standard deviation[16].

$$Effect\ Size = \frac{(M_{post,T} - M_{pre,T}) - (M_{post,C} - M_{pre,C})}{SD_{pre,pooled}}$$

Results, Discussion, and Conclusions

Table 3 summarizes the findings in comparing pre-test post-test responses of the treatment and control groups. Although not shown, comparing effect sizes (Cohen's d) across treatment and control groups on pre-survey responses, the results revealed that either small or very small effects were evident across the measures. Thus suggesting that the two groups were very similar in their responses during the pre-survey and there was no practical significance among them. Upon analyzing both post-test and pre-test responses for the treatment and control groups though, practical significance was evident. Nearly across all the measures, the difference between control and treatment groups suggested moderate to high practical significance. The only metric that did not reveal a moderate or high practical significance was sense of belonging. For all other measures, the treatment group revealed higher ratings than the control group and at least moderate practical significance. This suggests that the innovations implemented and the culture established in the classroom revealed practical significance in contrast to the control group. The implications of such findings have broad impacts to other senior design courses, but really all engineering courses.

Table 3: Treatment vs control group effect size results.

Construct	Effect Size	Summary of Results
Grit (4 items) (5pt scale)	0.30 **Moderate Effect**	Treatment group revealed grittier students than the control group.
Impulsivity (3 items) (7pt scale)	0.62 **Moderate to High Effect**	Treatment group less impulsive than control, revealing higher forethought during problem solving.
Sense of Belonging (3 items) (6pt scale)	0.20 **Small Effect**	Treatment group showed stronger sense of belonging than the control group.
Self-Efficacy (2 items) (7pt scale)	0.30 **Moderate Effect**	Treatment group revealed higher degree of self-efficacy than control group.
Mastery Approach (2 items) (7pt scale)	0.51 **Moderate to High Effect**	Treatment group revealed a higher degree of mastery orientation than control.
Performance Approach (3 items) (7pt scale)	0.30 **Moderate Effect**	Treatment group revealed a higher degree of performance orientation.
Work Avoidance (3 items) (7pt scale)	0.30 **Moderate Effect**	Treatment group less work avoidant than control group.

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