A FRAMEWORK FOR QUANTIFYING STUDENT SELF-CONFIDENCE AND TASK CHOICE IN ENGINEERING DESIGN-RELATED ACTIVITIES

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Introduction

Team-based projects are widely used in engineering courses [1], particularly product or process design courses in mechanical and civil engineering. While the intention of team-based design projects is to provide all students with a range of technical and non-technical mastery experiences [1,2] students enter into these experiences with differences – whether real or perceived – in relevant technical skills that undermine individuals' participation and persistence on team-based work. Prior research indicates male engineering students are more confident than females in their math and science abilities, as well as their abilities to solve open-ended problems [3-6]. Chachra and Kilgore [3] found the 'confidence gap' between males and females was more profound for open-ended problem solving than for math or science. They posited this gap was attributable to the team-based nature of design-oriented projects where feedback is more subjective and diffuse. Lower confidence in women often translates into lower likelihood that they will take an active role in technical tasks and instead relegate themselves to administrative or people-oriented tasks on design projects [7, 8]. However, Ingram and Parker [9] cautioned against stereotypical categorizations of male and female interactional styles. Their findings revealed that all-female teams did not display the "caring" or accommodating style typically assigned to females, and work ethic and team commitment played a stronger role in overall success. Moreover, several studies [7, 10, 11] found students in teams with a performance goal orientation (cf. learning goal orientation [12]) tended to divide tasks along gender-correlated lines in ways that undermine individuals' learning goals and reinforce minority status. In sum, students' self-perceptions, their mental models of success in engineering, and how they formulate their identities are critical to their persistence and success in engineering [13, 14]. Women and under-represented minorities (URM, def. non-white, non-Asian) are often the recipients of subtle messages of non-belonging, thus creating an inhospitable environment which inhibits the formation of professional identity [7].

Students make choices to complete particular academic tasks over others based on their learning orientation and their perceptions of the relevance of the task [15, 16]. Thus, studying students' task choices (e.g., roles on teams, how much time they spend on particular tasks) is essential for understanding how students' learning orientations change over time, and discerning the extent to which instructional interventions have an influence on students' learning orientations. Our study aligns with previous research on learning orientations, which indicates that the nature of the educational environment and the levels of support offered in academic tasks can encourage the adoption of different learning orientations [17, 18].

Although different terminology is applied to opposing motivators in learning, the underlying assumptions regarding these binaries are similar. On one hand, ego-orientation, performance goal, and performance orientation are viewed negatively because learners who fall in this group tend to be motivated by besting their peers on academic tasks and they tend to focus largely on grades instead of personal growth. Ego-oriented students view mastery as performing better than others based on external judgement; therefore, perceptions of ability are normatively referenced; they are motivated by competition, establishing superiority over others, and receiving high grades regardless of effort [19]. On the other hand, task orientation, learning goal, and mastery orientation are viewed positively because learners who fall into this group tend to be motivated by learning new things, are persistent in completing difficult or ambiguous academic tasks, and tend to use cognitive strategies to support learning such as metacognition and reflection [20, 21]. Task oriented students tend to view mastery as dependent on effort, and perceptions of ability are self-referenced [22]. Task oriented students focus their attention on the task, not on extrinsic rewards; learning, understanding, developing new skills, and problem-solving are motivators [17, 23]. Task orientation, like mastery orientation, is the most adaptive orientation for self-regulated learning [24, 7]. Task oriented students set self-improvement and learning as their goals; as a result, they are more likely to engage in various cognitive and behavioral activities that improve personal educational outcomes – establishing a productive work environment, using resources effectively, monitoring performance, managing time effectively, and seeking assistance when needed [25]. One eventual application of the framework proposed in this study is to promote task orientation among students because this orientation has been correlated with positive educational outcomes, such as retention in the field.

Self-efficacy and self-concept are two potential moderators of learning orientation [24, 26, 27]. Self-efficacy is positively correlated with self-regulated learning. Students who believe they can learn (personal efficacy) and perceive their efforts to learn will result in desired outcomes (outcome expectancy) are more likely to report the use of self-regulatory strategies associated with task orientation [28, 29]. By contrast, students with low self-efficacy may perceive that they can't learn the knowledge and skills necessary to be successful and/or will fail even if they work hard on a task. Research on self-efficacy [30, 31, 32] indicates that it plays an important role in academic motivation and persistence. Hirshfield and Chachra [34], for instance, suggested that student with low engineering self-efficacy may not take on more technical tasks in design projects.

In contrast to self-efficacy, which tends to be situation or context specific, e.g., [34, 35, self-concept is a larger, more encompassing construct with multiple mediators and moderators [36]. In our study, we focus on self-concept of knowledge and skills related to engineering – in particular, students' perceived math and science skills, interpersonal and communication self-confidence, open-ended problem-solving skills – as proxies of student self-concept. We acknowledge there are additional factors that influence students' overall self-concept; however, we have chosen these because they have been indicated as the most salient mediators of engineering self-concept based on previous research [3, 37]. Engineering application self-efficacy combined with selected academic self-concept constructs comprise our delineation of self-confidence, as shown in Figure 1. This delineation coheres with previous research, which indicates academic self-confidence as a more generalized belief in oneself, with the interplay of self-concept and self-efficacy acting in domain-specific contexts [11, 36].

We hypothesize that self-confidence and task choice on team-based engineering design projects leads directly to learning experiences for individual students that can either reinforce or undermine overall task orientation. These effects may be particularly pronounced for underrepresented students, specifically women in traditionally male-dominated engineering fields, students of color, and first-generation students. To address this hypothesis, we first need to develop a task orientation framework for synchronously quantifying students' task choice and self-confidence for team-based engineering design projects. This framework, which will be the focus of this study, leverages multiple validated instruments from the literature and combines them into two validated, multi-factorial outcomes – one for self-confidence and one for task choice – that are inherently aligned with each other as well as necessary elements of engagement in typical engineering projects. To facilitate visualization of individual students' outcomes across two multi-factorial measures, we also developed a complementary graphical representation of our task orientation framework.

Task Orientation Framework Design & Validation

The development of this task orientation framework began with the creation of holistic, validated instruments to quantify two constructs, self-confidence and task choice. For self-confidence, we developed an initial instrument by combining the well-established APPLES instrument [3, 7, 34], which focuses on self-confidence in interpersonal skills, problem solving, and math and science skills, with an established but unvalidated instrument [38] that measures self-confidence in tinkering and engineering applications. In the instrument [38], "tinkering" refers broadly to hands-on prototyping in both informal and formal learning settings. The combination of the two surveys allowed us to capture the entire range of typical learning outcomes of design-based projects. Exploratory and confirmatory factor analyses were conducted on data from a large pilot (N=602) of first-year engineering students. Data were collected during the first week of an introduction to engineering class, taken by all engineering students in their first semester regardless of discipline and taught by the same faculty across two identically sized sections. The instrument was shortened by eliminating items that did not correlate to a factor (low factor loadings) or correlated with multiple factors (high cross-loadings). The final version of the instrument (Table 1) was administered to another cohort of first semester engineering students from the same class the following year (N=632, 30.8% female and 14.0% URM), which yielded better fit (RMSEA=.058, CFI=.857) and high reliability on each factor (Cronbach's alpha ranging from .77 to .84). Five principal factors that encompass self-confidence on design-related tasks were measured in the final version of the survey: (1) open-ended problem solving; (2) interpersonal and communication skills; (3) math and science; (4) engineering application; and (5) tinkering.

Table 1: Final version of the self-confidence instrument, showing all survey items by factor (bold) as well as factor loadings for each item. The following prompt was used for all items: "Rate how well each statement describes you. 1-not descriptive at all, 2-somewhat not descriptive, 3-neutral, 4-somewhat descriptive, 5-very descriptive"

	Factor Loading
Tinkering	
I have the knowledge and technical skills to create engineered designs.	0.590
I innately know how engineered systems work, like machines, electronics, or structures.	0.749
I have experience working with a variety of fabrication tools and equipment.	0.725
I have a history of tinkering on personal design projects.	0.645
I can understand and utilize technical drawings and/or other design schematics.	0.686
I know what tools and equipment may be useful in creating a particular engineering design.	0.752
Math and Science	
I have a solid foundational knowledge of fundamental science principles, e.g., Newton's Laws, that I can utilize when solving engineering problems.	0.712
I feel confident in my ability to accurately work through geometry, algebra, and trigonometric calculations.	0.587
I have a solid foundational knowledge of advanced mathematics topics, like calculus or statistics, that I can utilize when solving engineering problems.	0.645
I can identify the fundamental science principles, e.g., conservation of energy or Ohm's Law, behind most engineering phenomena.	0.681
I can develop my own basic mathematical models to describe a pattern or phenomenon.	0.595
Open-Ended Problem Solving	
I can come up with multiple potential solutions to an engineering design problem.	0.706
I can justify why a particular engineering design concept would be the most feasible out of a set of potential concepts.	0.737
I feel confident in my ability to solve open-ended engineering design problems.	0.741
After developing a design solution, I can fairly evaluate whether it is working as intended.	0.670
I can set smaller, intermediate goals on design projects that lead towards a successful end product.	0.492
If someone gives me a very vague goal for a project, I can ask questions that will clarify the project goals and objectives.	0.438

Engineering Application	
I tend to create models in my mind or on paper of how a physical system will work.	0.560
I can apply engineering theory from my courses when designing solutions to problems.	0.679
I can reason out whether an engineered design, like a machine, structure, or process, will work as intended.	0.706
I can use my engineering background to select appropriate subcomponents for my design solution, like mechanical parts, materials, or electronic components.	0.718
I can apply estimation and/or back-of-envelope calculations to determine whether a design solution is reasonable.	0.658
Interpersonal and Communication Skills	
I am able to communicate technical information in written form clearly and concisely.	0.448
I feel confident when communicating my ideas and opinions in group settings.	0.722
When working in a group, I contribute an equal share or more of high quality work to the final product.	0.675
I am confident in speaking publicly about my technical knowledge and ideas.	0.627
I can serve in a leadership role on a group project, when required.	0.657
I can follow the lead of a teammate on a group project, when required.	0.539

A similar multi-factorial instrument was developed to quantify students' task choice. A complete set of project tasks was constructed by identifying overlapping categories across two prior instruments [7,34] and cross-referencing these tasks with common elements found in peer evaluations, student deliverables, and grading rubrics for engineering design courses at our institution and others [2]. This yielded eight task categories: (1) problem definition, (2) concept generation, (3) prototype fabrication, (4) design schematics, (5) engineering analyses, (6) design validation, (7) project management, and (8) technical communication. Our initial task choice survey, analogous in implementation to a prior study [34], was administered to the same cohort of students as our self-confidence CFA. It asked students to estimate post-hoc how many hours they spent on a particular task for the entirety of the project as well as the total time that their team spent on this task. This item structure led to numerous internal inconsistencies, most notably individual time contributions exceeding total team contribution; the item was subsequently redesigned to ask students for their self-assessed contribution relative to their teammates' average contribution for a particular task (1-5 Likert Scale with 1 = did not contribute, 2 = contributed less than team average, 3 = contributed equally to team average, 4 = contributed more than team average, and 5 = completed entire task by yourself). The final version of this task choice instrument was internally validated against peer evaluation scores for the same team-based project using the well-established CATME instrument [39]. A moderate but significant correlation ($r=0.30$, $p<0.05$) was found between subject-specific CATME peer evaluation scores and self-reported mean task choice performance.

Our task orientation framework also includes a complementary approach to graphically representing individual students' multi-factorial outcome for self-confidence and task-choice (Figure 1). Influenced by the Basadaur Profile [40], a graphical representation of personal creative problem-solving strategies, we represented each students' five-factor self-confidence score as a radar plot, normalized to maximum achievable values. A similar approach was taken to generate a visualization of students' eight-factor task choice outcomes. The axes for self-confidence and task choice were aligned by theme to facilitate direct comparison between the measures, e.g., task choice in "project management" aligned graphically with self-confidence in "interpersonal and communication skills." This graphical representation facilitates comparison between student mindset (self-confidence) and behavior on team-based projects.

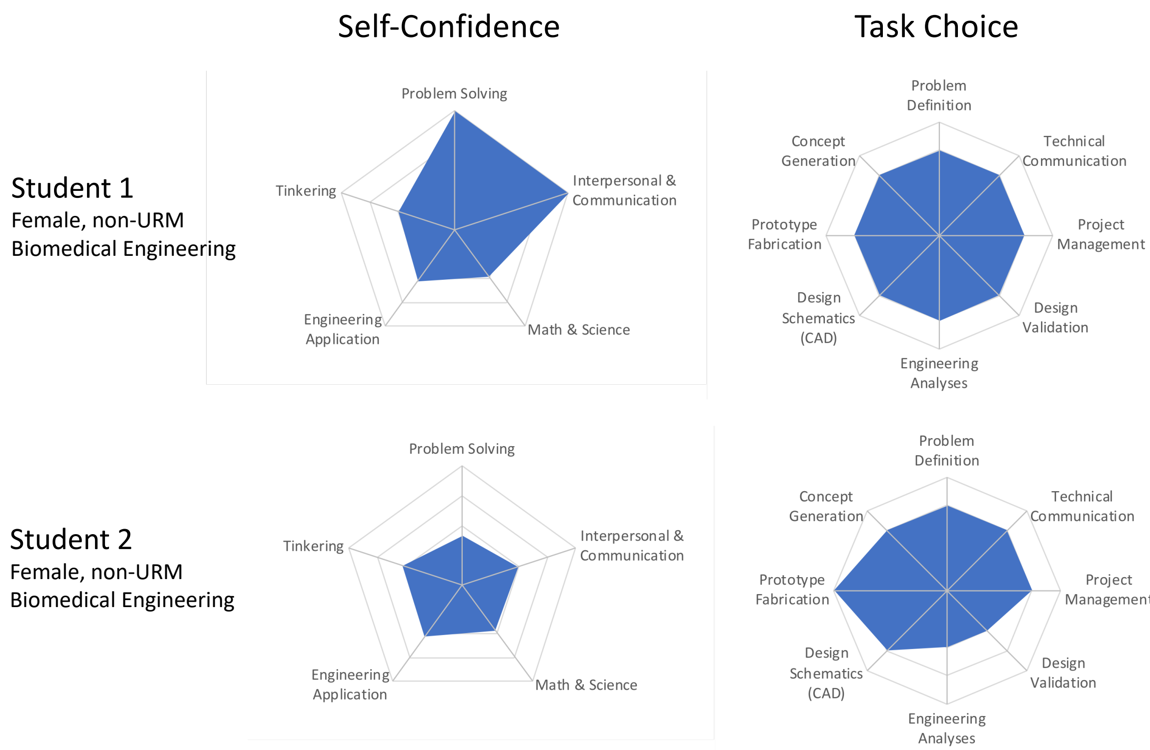

Figure 1: Self-confidence and task choice shown graphically using normalized radar plots for two demographically equivalent students from our data set (female, non-URM, biomedical engineering majors). Axes for the two measures were aligned thematically to facilitate both intra and inter-subject comparisons. For example, for the two students shown, Student 1 has higher than average self-confidence in problem solving and communication, and her self-reported task choice is uniformly above-average across all factors. In contrast, Student 2 reports lower than average self-confidence in all factors and demonstrates behavior skewed towards prototype fabrication.

Discussion

The framework introduced in this study includes two elements that will be valuable in future investigations of student engagement on team-based design projects. First, our measures of self-confidence and task choice, while built on prior work [3, 7, 34], are the first to reflect learning outcomes and task choices that encompass the entirety of the engineering design process. In future studies, we will use these measures to gain a deeper understanding of how students' participation in team-based projects is influenced by their project task choices, prior self-confidence as well as demographic variables such as race and gender. The second element of this work is the development of radar plots as graphical representations of multi-factorial factors of self-confidence and task choice on/by engineering team members, with individual students as the unit of analysis.

We anticipate that this tool will be useful for both instructors and students in identifying individual students' strengths and opportunities for growth as they engage with their peers on team-based design projects. We propose the practical applications of the task orientation framework are threefold. First, we posit that providing individual students with a report on their task orientation profile, compiled from their responses to survey items, will provide them with an explicit awareness of their strengths and opportunities for growth as engineers. Moreover, composite profiles of students in courses during each academic term would provide instructors with empirical information about overall task orientations of students. Thus, instructors could use profile information to make timely, proximal instructional decisions about interventions and strategies that might motivate students and support their growth as engineers. Third, the task orientation framework could be used for future studies on teaming, which this research group intends to pursue. For instance, using the task orientation framework, instructors for courses that include team-based design projects might use individual students' profiles to group them into homogeneous or heterogeneous teams, and then study the effects of these groupings on students' task orientations. This type of research would inform others working in postsecondary engineering education about optimal strategies that support student success and retention in engineering programs of study.

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