Measuring Undergraduate Student Design Self-Efficacy within an Undergraduate Civil Engineering Curriculum

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Introduction

As infrastructure is becoming deteriorated and outdated, there is a need for diverse, design-savvy civil engineers to develop the infrastructure of the future. In fact, the American Society of Civil Engineers has issued a grade of D+ for America's infrastructure and declared a need for more diverse civil engineering talent to tackle the complex issues related to our infrastructure systems [1, 2]. Training students to develop design thinking and skills will allow them to enter professional practice ready to participate in the challenge of infrastructure re-design. Indeed, ABET requires that students have "an ability to apply engineering design to produce solutions…" upon graduation [3]. Perhaps the most effective way to guide students in developing design skills is through engagement in real-world projects. Furthermore, providing authentic design experiences in a supportive educational environment that encourages success can build self-efficacy (one's beliefs in their ability to achieve specific tasks), which in turn fuels motivation to succeed as an engineer [4]. Promoting engineering self-efficacy is a promising strategy for retaining diverse student populations, as prior work has shown that low self-efficacy is often a contributor to attrition [5, 6].

Within an undergraduate curriculum at a small, teaching-focused institution in the southeast, an integrated student outcome thread focused on development of civil engineering design skills was adopted and mapped by faculty across a series of 16 departmental courses. The design outcome thread encompasses instructional material from courses in 1) Introduction to Civil and Environmental Engineering, 2) Dynamics, 3) Geomatics Lab, 4) Highway Engineering, 5) Mechanics of Materials, 6) Hydrology and Hydraulics, 7) Asphalt and Concrete Laboratory, 8) Measurements, Analysis and Modeling of Civil Engineering Systems, 9) Reinforced Concrete Design, 10) Geotechnical Engineering Lab, 11) Steel Design, 12) Water and Wastewater Systems, 13) Geotechnical Engineering II, 14) Fluid Mechanics Laboratory, 15,16) two-course sequence in Civil Engineering Capstone Design. Data from course embedded indicators supports reasonable student mastery of design skills [7]. It is hypothesized that students' successful engagement in design experiences positively impacts their engineering self-efficacy, which may increase motivation to engage in professional practice.

The goal of this study is to explore the engineering design self-efficacy of civil engineering students engaged in a design thread integrated throughout the Civil and Environmental Engineering (CEE) curriculum at The Citadel. Self-efficacy data was collected using a previously-published survey instrument. The following research questions were addressed and insights for improving civil engineering education at The Citadel and beyond are provided.

1. To what extent are results from the design self-efficacy instrument valid for undergraduate civil engineering students?
2. How does design-related self-efficacy and related self-concepts vary among civil engineering undergraduates from different academic classes?
3. Which steps in the engineering design process do students report the highest and lowest self-efficacy?

Relevant Literature

Engineering Design Process

Design is a fundamental component of the engineering profession [8] and consequently, engineering education [9]. In fact, design is often thought of as "what engineers do" [8]. Many definitions of engineering design have been presented. For instance, Skerlos, Morrow, & Michalek [10] describe it as "a creative decision-making process that aims to find an optimal balance of trade-offs in the production of an artifact that best satisfies customer and other stakeholder preferences." Even still, Dym et al. [8] characterize it as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints." One common element of these definitions is that design is a process. The Massachusetts Department of Education Science and Technology/Engineering Curriculum Framework presents one version of the engineering design process (Figure 1) [11].

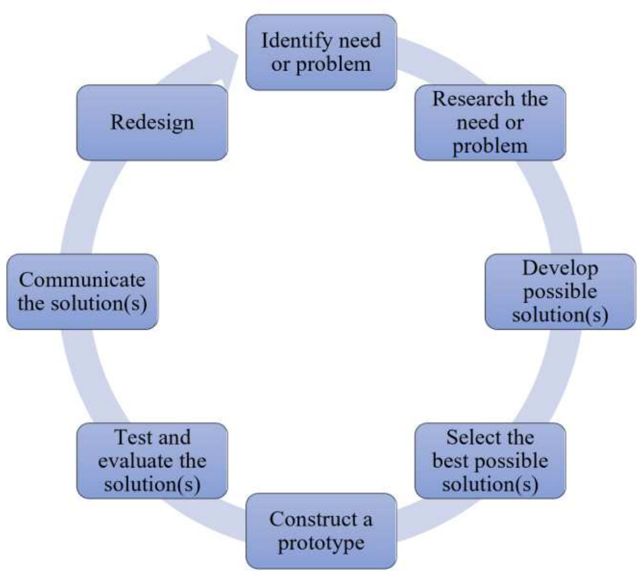

Figure 1. Engineering design process (adapted from [11, 12])

Self-Efficacy Framework

Self-efficacy is one's own personal judgements about their abilities to achieve specific goals [4]. According to Bandura's Self Efficacy Framework [13], there are several types of information that can influence self-efficacy. The most impactful sources of self-efficacy are *mastery experiences*, which refer to one's direct experience of success or failure. Interaction with role models and seeing others' successful performances, or *vicarious experiences*, can also lead to improvement of self-efficacy. Compliments or criticisms (*social persuasions*) can build or deteriorate one's self-efficacy. Finally, people's perceptions of their *physiological arousal* can impact their self-efficacy, with intense stress often indicating future failure.

Commonly, self-efficacy is often misinterpreted as confidence [14]. While both self-efficacy and confidence include the strength of belief in one's abilities, efficacy also incorporates a specific level of achievement [15]. Hutchison et al. [14] provides a clarifying example: "I am confident in my mathematical abilities" is a confidence statement, while "I am confident I can correctly solve calculus problems" is an efficacy statement. Despite the differences in the two self-concepts, some studies elicit perceptions of confidence from participants because people are unable to conceptualize self-efficacy [12, 16].

Self-efficacy is related to several other self-concepts. For instance, high self-efficacy to complete tasks often leads to increased motivation to achieve those tasks [4]. In addition, outcome expectancy (results one anticipates as a result of performing a task) and anxiety (self-doubt related to performing a task) are also known to impact self-efficacy [12, 17]. Indeed, Bandura stated that "people's level of motivation, affective states, and actions are based more on what they believe that on what is objectively true" [18].

Self-Efficacy and Engineering Education

Self-efficacy has been shown to be an important predictor of students' persistence and performance in engineering, more so even that past achievements [5, 6]. One study found that self-efficacy impacted performance in engineering, while effort and critical thinking did not [19]. Even still Marra et al. [20] summarize that self-efficacy may be an important factor impacting persistence of female and minority students in engineering. Besterfield-Sacre et al. [21] also report that females who remain in engineering report lower self-efficacy than their male peers. Consequently, methods for improving self-efficacy may be an effective strategy for reducing attrition, especially among diverse student groups. As such, instruments and methods to quantify self-efficacy are important tools for informing the design of engineering education experiences.

Mamaril et al. [22] summarizes that there are three groups of self-efficacy measures used in engineering. First, general academic self-efficacy scales are used to gage students' perceptions of their abilities to achieve academic success. Second, domain-general self-efficacy instruments prompt students to consider their ability to achieve in engineering, but without reference to specific engineering tasks. For example, "How much confidence do you have in your ability to excel in your engineering major over the next semester?" [23] is domain-general. Finally, task- or skill-specific self-efficacy measures ask students to consider their efficacy to complete specific engineering tasks or demonstrate engineering skills. Carberry et al. [12] presents an instrument that measures self-efficacy (and other self-concepts) related to specific steps in the engineering design process (Figure 1). Carberry et al. [12] administered their instrument to participants with varying levels of design experience (practicing engineers, engineering education graduate students, engineering students, non-engineers with a science background, and non-engineers without a science background) and found the collected data to be a valid measure of design self-efficacy.

Institutional Context

The CEE department at The Citadel provides students with a high-caliber educational experience in a unique leadership-focused, military environment. The department was established in 1912 and the civil engineering degree has been accredited since 1936. The department's curriculum emphasizes development of principled engineering leaders who are equipped to play a crucial role in the planning, design, construction, maintenance, and operation of public infrastructure to establish healthy, vibrant communities. Table 1 includes a list of all twenty-two program outcomes adopted by Department faculty. Outcomes are also mapped to Bloom's cognitive taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation) to establish levels of competency students should attain across specified program outcomes [24].

Table 1. Summary of program outcomes in Civil and Environmental Engineering at The Citadel.

Dept. Program Outcome	Description	Dept. Program Outcome	Description
1	Mathematics	9a	Breadth, Environmental
2	Natural Science	9b	Breadth, Structural
3	Mechanics	9c	Breadth, Geotechnical
4	Experiments	9d	Breadth, Transportation
5	Problem Solving	10	Communication
6a	Design, Environmental	11a	Public Policy
6b	Design, Structural	11b	Business
6c	Design, Geotechnical	12	Leadership
6d	Design, Transportation	13	Interdisciplinary Teams
7	Contemporary Issues	14	Self-Directed Learning
8	Project Management	15	Ethical Responsibility

The undergraduate curriculum focuses on application of rigorous analysis methods, comprehensive evaluation of equitable societal needs, adherence to relevant guidelines and standards, and determination of optimal solutions to complex engineering problems. Table 2 depicts an undergraduate student's design experience across the undergraduate curriculum.

Obviously, a student's exposure to design complexities increases as the student advances towards graduation. Typically, the freshmanexperience is limited in scope, but open-ended enough to create a context where students can begin developing an understanding of what the "design process" entails. Students undertake disciplinary projects (e.g., design of a parking lot, building layout or structural design) where teamwork, communication and collaborative problem-solving skills are emphasized.

Sophomore year offers more opportunity for students to engage in foundational engineering courses; however, most of these courses do not lend themselves to incorporating a design experience. Instructors from two courses, however, have taken creative approaches to incorporate design. In dynamics, students are required to design an experiment to measure any dynamic system that they choose. The experiment and results are documented in a report. In the geomatics laboratory, students create a 3D model of a selected site and design the site to meet specified criteria. The process involves creating a building pad and grading surface for the site to calculate cut and fill volumes using AutoCAD Civil 3D.

It is during the junior year that students are afforded an opportunity to better engage in engineering design projects, because those students have completed most of their introductory and foundational course and are now mostly taking courses in their major field of study. Students engage in design in several courses: Highway Engineering; Mechanics of Materials; Hydrology and Hydraulics; Asphalt and Concrete Lab; Measurements, Analysis, and Modeling of Civil Engineering Systems.

Senior year is the most intensive for design opportunities in the curriculum. Students take geotechnical engineering, reinforced concrete, steel design, water and wastewater system design, and fluid mechanics laboratory. Students also take a two-course sequence in civil engineering capstone design that offers the most realistic experience available during their four years of undergraduate study. Teamwork and communication skills are included as part of this experience, along with addressing social, environmental, political and sustainability issues.

Table 2. Course Instruction and Design Outcomes in the Civil Engineering Curriculum[1]

Course	Credits	Course Name	Design Elements
CIVL 103	1	Introduction to Civil and Environmental Engineering	Open ended projects at the freshman level, including design of a parking lot, water filter, and bridge
CIVL 203	3	Dynamics	Students design an experiment to measure a dynamic system of interest
CIVL 239	1	Geomatics Lab	Students survey and create a 3D model of a given site. Students develop and design the site to given criteria
CIVL 302	3	Highway Engineering	Comprehensive highway design, including alignments, superelevation design, pipe culvert designs, and basic cost calculations
CIVL 304	3	Mechanics of Materials	Students select a design problem of interest that is related to course topics and concepts
CIVL 321	3	Hydrology and Water Resources	Stormwater runoff generation and system design
CE 327	1	Asphalt and Concrete Lab	Portland cement concrete & hot mix asphalt designs
CIVL 330	3	Measurements, Analysis, and Modeling of CE Systems	Computer simulations for design (e.g., designing treatment process for a wastewater plant).
CE 404	3	Reinforced Concrete Design	Design of structural concrete members including capstone type project: design of a retaining wall.
CIVL 402	1	Geotechnical Engineering Lab	Design a lab experiment to determine an appropriate, quantitative relationship between void ratio and hydraulic conductivity of sand
CIVL 406	3	Steel Design	Design of spread footings for column demands from an actual building.
CIVL 408	3	Water and Wastewater Systems	(1) Design a sedimentation basin based on defendable water demand (2) Design selected pipes in a sanitary sewer system (including diameters, slopes, and connections to an existing main)
CIVL 410	3	Geotechnical Engineering II	(1) Design a deep foundation; (2) design a shallow foundation; and (3) design a retaining wall for a proposed building on campus.
CIVL 418	1	Fluid Mechanics Lab	Water distribution system network design

CIVL 432	3	CE Capstone Design I	Alternative comparison, matrix selection of preferred alternative, wetlands permit, 30% complete design.
CIVL 433	3	CE Capstone Design II	Design of intradisciplinary infrastructure project including structural, geotechnical, environmental, & transportation engineering

[1]Additional information about the undergraduate CEE curriculum at The Citadel is available online [25].

Methods

Survey Development and Administration

First, participants were asked to provide demographic information, including their names (for tracking purposes), student group (cadets, active duty/veterans, evening students), and GPA. Second, students were prompted to provide an open-ended description of the design process (which is not examined as part of this study).

The design self-efficacy instrument developed by Carberry et al. [12] was adapted and used to capture design self-efficacy and related self-concepts for undergraduate civil engineering students. The modified instrument measured the self-concepts of self-efficacy, motivation, outcome expectancy, and anxiety using two different approaches. First, students rated their self-concept to *conduct engineering design* using a seven-point scale (termed "overall design" self-concept). Second, students rated their self-concept related to each of the eight steps in the design process (Figure 1) using a seven-point scale. As described by Carberry, the average ratings across the eight steps for each of the self-concepts provides another metric for design self-concept (termed "design process" self-concept). Consequently, each of the four self-concept scales included nine items rated on seven-point scales.

In accordance with the approved Institutional Review Board (IRB) protocol, the survey was administered to all civil engineering undergraduates before midterms during the Spring 2019 semester. In total, 153 students completed the survey (69.9% of total undergraduate population) (Table 3). Most students (n = 141) participated via Google Forms, although 12 sophomores completed paper surveys. Of the 153 participants, 24.8% were freshmen, 21.6% were sophomores, 27.5% were juniors, and 26.1% were seniors. In addition, 6.5% of respondents reported their gender as female. In total, 84.3% were in the Corps of Cadets, 11.8% identified as evening students, and 3.9% were active duty or veteran students.

Table 3. Survey participants by academic class.

	Population Total	No. Participants	% of Population	% of Sample
Freshmen	58	38	65.5	24.8
Sophomores	57	33	57.9	21.6
Juniors	42	42	100	27.5
Seniors	62	40	64.5	26.1
Total	219	153	69.9	100

Data Analysis

Internal consistency of the self-efficacy, motivation, outcome expectancy, and anxiety scales were evaluated using Cronbach's alpha. Values for the self-efficacy, motivation, outcome expectancy, and anxiety scales were 0.969, 0.957, 0.954, and 0.966, respectively. Cheung [26] describes that Cronbach's alpha above 0.9 are "excellent."

Relevant correlations were determined using Pearon's r and interpreted based on benchmarks reported by Portney and Watkins [27]. Specifically, correlations between the two measures of design self-efficacy (overall design and design process) were determined. In addition, correlations between overall design self-concepts were computed. Correlation data was used to describe the self-concepts of participants, as well as provide evidence for validity.

The impact of academic year on overall design self-concepts was captured using one-way Analysis of Variance (ANOVA). If a significant trend was detected, a Tukey post-hoc test was used to identify the specific academic years that varied in self-concept. For all inferential statistical tests, a significance threshold (p) of 0.05 was used.

Finally, quartile coding was used to examine how self-concepts related to each step in the engineering design process differed between freshmen and seniors. Averages for each of the eight design tasks (Figure 1) were calculated for the two academic classes. Next, the averages were sorted by quartile, with averages in the first, second, third, and fourth quartiles designated as *minimal, low, high,* and *very high* self-concepts, respectively.

Results

Relationship between Design and Design Process Self-Efficacy

Student self-concept ratings related to *conduct[ing]engineering design* (referred to as "overall design") were related to their self-concept ratings for each step in the engineering design process (Table 4). In fact, within each of the four self-concept scales, most correlations between overall design and design tasks were "good to excellent" [27]. Furthermore, averages for the eight steps in the design process across all four self-concept scales were highly correlated, indicating that responses were consistent across the two methods for soliciting design self-concepts. ***Consequently, further analyses will use overall design ratings, unless data related to the individual steps in the design process enriches the discussion.***

Table 4. Correlations between design and design process self-concept scores[a,b] (*n* = 153).

	Overall Design Self-Efficacy	Overall Design Motivation	Overall Design Outcome Expectancy	Overall Design Anxiety
Identify a design need	0.809	0.877	0.536	0.831
Research a design need	0.752	0.724	0.512	0.729
Develop design solutions	0.830	0.816	0.551	0.834
Select the best possible design	0.768	0.776	0.470	0.827
Construct a prototype	0.689	0.637	0.469	0.790
Evaluate and test a design	0.737	0.701	0.487	0.782
Communicate design	0.751	0.685	0.490	0.678
Redesign	0.790	0.723	0.512	0.806
Design Process Average	0.851	0.862	0.555	0.885

[a]The Carberry et al. [12] instrument allows for two measures of self-concepts. Overall design refers to the average rating (on a seven-point scale) related to self-concept to *conduct engineering design*. Design process refers to the average self-concept across the eight design tasks.
[b]$p \leq 0.001$ for all correlations shown.

Relationships Between Design Self-Concepts

Design self-efficacy was significantly correlated with motivation, outcome expectancy, and anxiety (Table 5). According to Portney and Watkins [27], self-efficacy had a "good to excellent relationship" with outcome expectancy and a "moderate to good relationship" with motivation. However, there was "little or no relationship" with anxiety.

Table 5. Correlations between self-efficacy and related self-concepts (*n* = 153).

	Motivation	Outcome Expectancy	Anxiety
Self-Efficacy	0.435***	0.448***	-0.190*
Motivation		0.195*	-0.081
Outcome Expectancy			-0.149

**$p \leq 0.01$; ***$p \leq 0.001$

Impact of Academic Class on Overall Design Self-Concepts

Overall design self-efficacy generally increased with increasing academic year (Figure 2A). According to a one-way ANOVA, there was a statistically significant difference in overall design self-efficacy based on academic year [$F(3, 149) = 7.132$, $p \leq 0.001$]. A Tukey post hoc test revealed no difference in overall design self-efficacy between freshmen (3.8 $\pm$ 1.7) and sophomores (3.8 $\pm$ 1.3, $p = 0.993$). Similarly, there was no difference in overall design self-efficacy between juniors (4.7 $\pm$ 1.1) and seniors (4.9 $\pm$ 1.4, $p = 0.981$). However, overall design self-efficacy for freshmen was lower than for juniors ($p = 0.016$) and seniors ($p = 0.006$). Similarly, overall design self-efficacy for sophomores was lower than for juniors ($p = 0.010$) and seniors ($p = 0.003$). Consequently, the overall design self-efficacy of freshmen and sophomores was lower than for junior and seniors (Table 6). Other design self-concepts did not vary significantly with academic year (Figure 2B-D).

Table 6. Variation of self-efficacy and other self-concepts based on academic year.

	Self-Efficacy[a]		Motivation		Outcome Expectancy		Anxiety	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD
Freshmen ($n = 38$)	3.8	1.7	5.7	1.3	4.3	1.7	4.1	1.6
Sophomores ($n = 33$)	3.8	1.3	5.0	1.2	4.2	1.5	3.7	1.3
Juniors ($n = 42$)	4.7	1.1	5.5	1.3	4.8	1.2	3.4	1.5
Seniors ($n = 40$)	4.9	1.1	5.3	1.4	4.9	1.3	3.8	1.6
Total ($n = 153$)	4.1	1.5	5.4	1.3	4.6	1.4	3.7	1.5

[a]Self-efficacy varied significantly based on academic class. Self-efficacy for freshmen and sophomores was significantly lower than for juniors and seniors.

Impact of Academic Year on Self-Concepts Related to Engineering Design Process

Quartile analysis was used to examine how self-concepts related to each step in the engineering design process differed between freshmen and seniors (Table 7). In general, self-efficacy and outcome expectancy were higher for seniors, as compared to freshmen. However, motivation to complete each design step was *high* or *very high* for all students. Anxiety averages were generally lower than averages for other self-concepts for both freshmen and seniors.

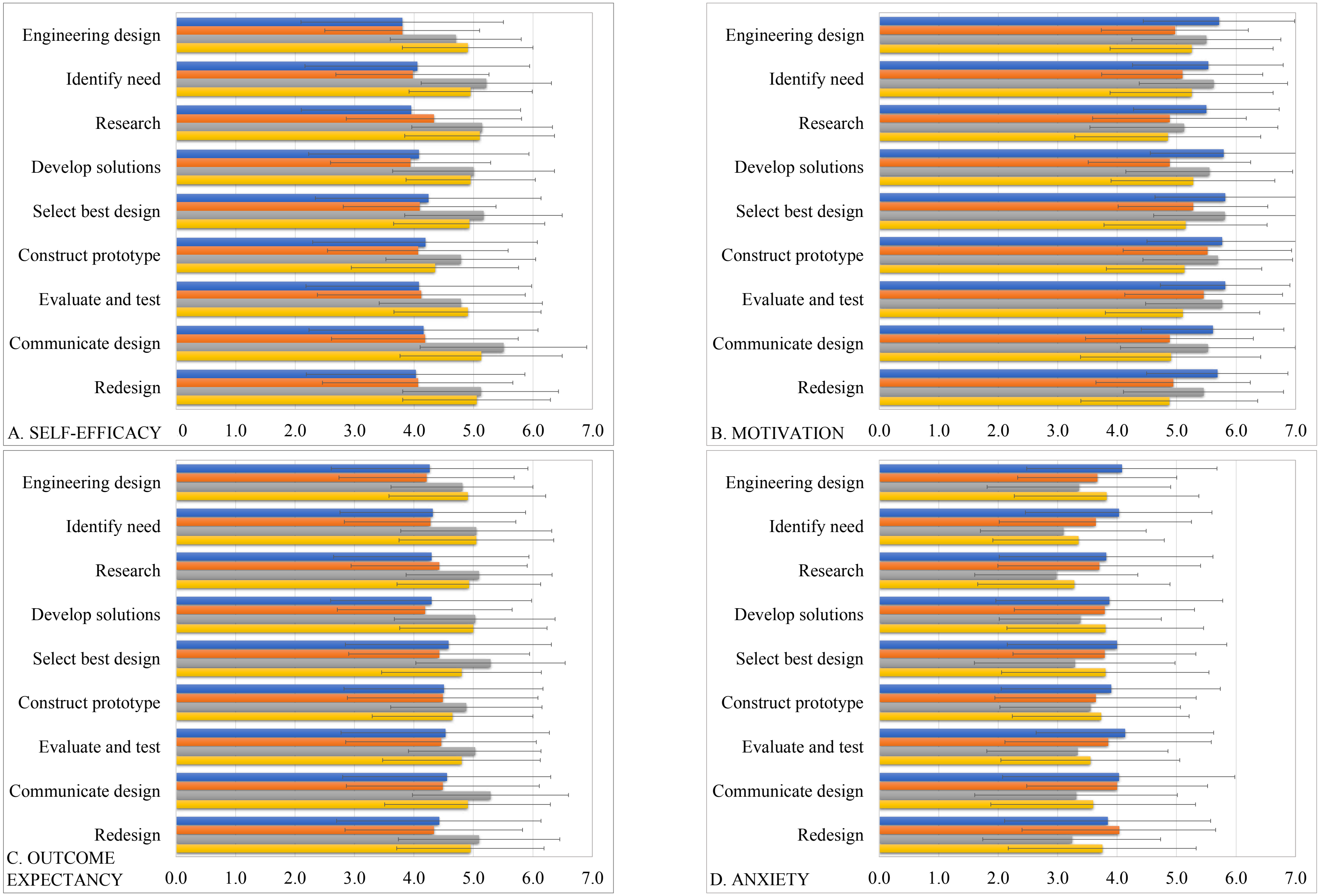

Figure 2. (A) Self-efficacy, (B) motivation, (C) outcome expectancy, and (D) anxiety ratings for design tasks by academic class [Bars from top to bottom: Freshmen (blue), Sophomores (orange), Juniors (gray), Seniors (yellow)].

Table 7. Freshmen and senior self-concepts for completing each step in the engineering design process (based on quartile coding[1]).

	Self-Efficacy		Motivation		Outcome Expectancy		Anxiety	
	FR	SR	FR	SR	FR	SR	FR	SR
Identify need	Low	High	High	High	Low	High	Low	Minimal
Research	Minimal	High	High	High	Low	High	Minimal	Minimal
Develop solutions	Low	High	High	High	Low	High	Minimal	Minimal
Select best design	Low	High	Very High	High	High	High	Minimal	Minimal
Construct prototype	Low	Low	High	High	Low	High	Minimal	Minimal
Evaluate and test	Low	High	Very High	High	Low	High	Low	Minimal
Communicate design	Low	High	High	High	Low	High	Low	Minimal
Redesign	Low	High	High	High	Low	High	Minimal	Minimal

[1]Averages for each step across all four scales were sorted by quartile, with averages in the first, second, third, and fourth quartiles designated as *minimal, low, high,* and *very high* self-concepts.

Discussion

To what extent are results from the design self-efficacy instrument valid for undergraduate civil engineering students?

Overall, the Carberry et al. [12] instrument allows for reliable and consistent measurement of design self-concepts among undergraduate civil engineering students. First, Cronbach's alpha for the self-efficacy, motivation, outcome expectancy, and anxiety scales were above 0.9, which indicates high internal consistency. Second, students' self-concept ratings for overall engineering design were highly correlated (Pearson's $r \geq 0.85$) with their average self-concept ratings for each of the eight steps in the engineering design process (Table 4). As also concluded by Carberry et al. [12], the selected Massachusetts Science and Technology/Engineering Curriculum Framework is an adequate model for representing engineering design (i.e., content validity).

Evidence supports construct validity for design self-efficacy measured using the Carberry et al. [12] instrument for undergraduate civil engineering students. Construct validity means that the instrument captures theoretically-supported relationships. In the current study, overall design self-efficacy was significantly ($p \leq 0.05$) correlated with motivation, outcome expectancy, and anxiety (Table 5). Motivation ($r = 0.435$) and outcome expectancy ($r = 0.448$) were positively related to self-efficacy, while anxiety ($r = -0.190$) was negatively related. However, the magnitude of self-efficacy correlations with other self-concepts for this study were lower than reported by Carberry et al. [12], perhaps because the later team sampled a group more variation in engineering experience, including engineers, non-engineers, students, and professionals.

Some evidence exists for criterion-related validity, or the ability of an instrument to predict a related criterion for the participants. Foremost, the instrument was able to capture significant differences in overall design self-efficacy between freshmen/sophomores and junior/seniors (Table 6). However, unlike the Carberry et al. [12] team, no significant differences in other self-concepts were found based on academic class. Again, the Carberry et al. [12] team sampled a much more diverse group of respondents (engineers, non-engineers, students, and professionals) which likely had a greater variation in design self-concepts than the rather uniform group of civil engineering undergraduates in the current study.

How does design self-efficacy, motivation, outcome expectancy, and anxiety vary among civil engineering undergraduates from different academic classes?

Based on reports of self-concepts related to *conduct[ing] engineering design* (overall design), only self-efficacy varied statistically with academic year. Self-efficacy for juniors and seniors was significantly higher than for freshmen and sophomores (Table 6). The average self-efficacy rating of civil engineering undergraduates for overall design was 4.1 ± 1.5 ($58.6 \pm 21.4\%$, based on seven-point scale), which is similar to the average reported by Carberry et al. [12] for engineering students and non-engineers with science backgrounds ($54.4 \pm 26.0\%$). Consequently, the overall design self-efficacy for civil engineering students engaging in an integrated design sequence is on par with engineering and science majors elsewhere.

Based on quartile analysis of average self-concept ratings for each step in the engineering design process, several trends were noted between freshmen and seniors (Table 7). Freshmen tended to report "low" self-efficacy and outcome expectancy for all steps, while seniors tended to report "high" self-efficacy. The only exception is for self-efficacy related to *construct a prototype*, for which both freshmen and seniors reported low self-efficacy. Indeed, the design sequence at The Citadel does not include construction of physical prototypes, as the major focus of design projects is on large infrastructure. Students may not have recognized computer models and simulations as prototypes.

Quartile analysis of average motivation ratings showed that motivation related to some steps in the design process were lower for seniors as compared to freshmen, although all were designated as "high" or "very high." Interestingly, freshmen were most motivated about *select[ing] the best design* and *evaluat[ing] and test[ing]*, which may indicate that they are interested in solving the problem being addressed.

Quartile analysis of average anxiety ratings showed that anxiety related to some steps in the design process were higher for freshmen as compared to seniors, although all were designated as "minimal" or "low." It is likely that as students practice engaging in the design process through the design sequence, their anxiety decreases. Average anxiety ratings for design steps ranged from 3.0 to 4.1 (Figure 2D). Indeed, Carberry et al. [12] presents that the responsibility of engineers to provide safe and effective designs for the public likely leads to even experienced professionals retaining some degree of anxiety.

Which steps in the engineering design process do students report the highest and lowest self-efficacy?

Self-efficacy scores across all sampled civil engineering students (given similar trends between academic classes for all design steps, Figure 2D) show similar averages for each step in the design process. Indeed, averages ranged from 4.4 to 4.8, which is appropriate (on a seven-point scale) for undergraduates who have not engaged in significant engineering practice (Figure 3). In other words, practicing professionals, not undergraduate students would be expected to rate their self-efficacy at the top of the seven-point scale. Despite the low variability in average self-efficacy scores, it is evident that less technical steps (i.e., *communicate design, research, and identify need*) have lower average self-efficacy ratings that more technical steps (i.e., *develop a solution*, *evaluate and test*, and *construct a prototype*.

- Communicate Design ($M = 4.8$)
- Research ($M = 4.7$)
- Identify Need ($M = 4.6$)
- Redesign ($M = 4.6$)
- Select Best Design ($M = 4.6$)
- Develop Solutions ($M = 4.5$)
- Evaluate and Test ($M = 4.5$)
- Construct prototype ($M = 4.4$)

Figure 3. Rank order of self-efficacy related to design tasks for all participants.

Conclusions

A study was conducted to explore the self-efficacy and related self-concepts of undergraduate civil engineering students engaging in an integrated design sequence. Self-efficacy, motivation, outcome expectancy, and anxiety related to *conducting engineering design* and each of the eight steps in the engineering design process were measured using seven-point scales through an online survey. The following conclusions were made based on the results.

1. Reasonable evidence supports that the self-efficacy instrument provides reliable (based on Cronbach's alpha) and valid (content, construct, and criterion-related) data for undergraduate civil engineering students.
2. The design sequence provides mastery experiences for students which likely leads to development of self-efficacy. Self-efficacy related to *conducting engineering design* was statistically higher for upperclassmen (juniors/seniors) than for underclassmen (freshmen/sophomores) and on par with reports for other similar undergraduates.
3. Based on quartile analysis, the design sequence helps to develop self-efficacy, decrease anxiety, and maintain motivation between freshmen and senior years.
4. Rank order of average self-efficacy scores related the eight steps in the design process may suggest higher self-efficacy related to non-technical design steps, as compared to technical design steps. Further work is needed to examine whether this trend is due to inclusion of non-technical design steps in the design sequence or student beliefs that non-technical steps are easier to complete than technical ones.

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Appendix A

Design Self-Efficacy Survey

The design self-efficacy instrument developed by Carberry et al. [12] was adapted and used to capture design self-efficacy and related self-concepts for undergraduate civil engineering students. The modified instrument measured the self-concepts of self-efficacy, motivation, outcome expectancy, and anxiety using two different approaches. First, students rated their self-concept to *conduct engineering design* using a seven-point scale (termed “overall design” self-concept). Second, students rated their self-concept related to each of the eight steps in the design process using a seven-point scale. As described by Carberry, the average ratings across the eight steps for each of the self-concepts provides another metric for design self-concept (termed “design process” self-concept). Consequently, each of the four self-concept scales included nine items rated on seven-point scales.

Design Self-Efficacy

You are being asked to complete a brief survey about your beliefs in your ability to complete several design-related tasks. By continuing this survey, you consent for your responses to be used for research purposes. While results from this study will be publicly reported, scores will be aggregated, which means that your scores will never be shown in conjunction with your name or any other identifying data. All responses will be saved in a password protected spreadsheet and not be connected to your name. Only Dr. Davis and Dr. Watson will have access to this data. At the conclusion of the project, your responses will be destroyed. If you have any questions, please contact Dr. Mary Katherine Watson at mwatson9@citadel.edu.

* Required

About You

1. **First Name:** *

2. **Last Name:** *

3. **What is your gender?**
Mark only one oval.
- Male
- Female
- Prefer not to say

4. **What is your major?**
Mark only one oval.
- Civil Engineering
- Construction Engineering

5. **Which group of students do you primarily identify with?**
Mark only one oval.
- Corps of Cadets
- Evening Students
- Veteran/Active Duty Students

6. **What is your overall Citadel GPA?**
Mark only one oval.

- ⬭ 4.00
- ⬭ 3.50 - 3.99
- ⬭ 3.00 - 3.49
- ⬭ 2.50 - 2.99
- ⬭ 2.00 - 2.49
- ⬭ 1.50 - 1.99
- ⬭ Less than 1.50
- ⬭ No Citadel GPA available (i.e., I am a freshman)

7. **What is your major GPA (either in civil or construction engineering)?**
Mark only one oval.

- ⬭ 4.00
- ⬭ 3.50 - 3.99
- ⬭ 3.00 - 3.49
- ⬭ 2.50 - 2.99
- ⬭ 2.00 - 2.49
- ⬭ 1.50 - 1.99
- ⬭ Less than 1.50
- ⬭ No Citadel GPA available (i.e., I am a freshman)

Please answer the following question without consulting any resources (e.g., the internet, your peers, etc.)

8. **Describe the engineering design process, in your own words.**

9. **Rate your degree of confidence (i.e., belief in your current ability) to perform the following tasks:** *
Mark only one oval per row.

	1: Cannot do at all	2	3	4: Moderately can do	5	6	7: Highly certain can do
Conduct engineering design							
Identify a design need							
Research a design need							
Develop design solutions							
Select the best possible design							
Construct a prototype							
Evaluate and test a design							
Communicate a design							
Redesign							

10. **Rate how motivated you would be to perform the following tasks:** *
Mark only one oval per row.

	1: Not motivated	2	3	4: Moderately Motivated	5	6	7
Conduct engineering design							
Identify a design need							
Research a design need							
Develop design solutions							
Select the best possible design							
Construct a prototype							
Evaluate and test a design							
Communicate a design							
Redesign							

11. **Rate how successful you would be in performing the following tasks:** *
Mark only one oval per row.

	1: Cannot expect success at all	2	3	4: Moderately expect success	5	6	7: Highly certain of success
Conduct engineering design							
Identify a design need							
Research a design need							
Develop design solutions							
Select the best possible design							
Construct a prototype							
Evaluate and test a design							
Communicate a design							
Redesign							

12. **Rate your degree of anxiety (how apprehensive you would be) in performing the following tasks:** *
Mark only one oval per row.

	1: Not anxious at all	2	3	4: Moderately anxious	5	6	7: Highly anxious
Conduct engineering design							
Identify a design need							
Research a design need							
Develop design solutions							
Select the best possible design							
Construct a prototype							
Evaluate and test a design							
Communicate a design							
Redesign							