Paper ID #32085

Exploring Math Self-Efficacy Among First-Year Civil Engineering Majors

Dr. Mary Katherine Watson, The Citadel

Mary Katherine Watson is currently an Associate Professor of Civil and Environmental Engineering at The Citadel. She holds BS and MS degrees in Biosystems Engineering from Clemson University and a PhD in Environmental Engineering from The Georgia Institute of Technology. She enjoys, and has invested significantly, in the development of her undergraduate students, serving as past faculty advisor for numerous student groups. Dr. Watson is passionate about improving access to engineering education and serves as the faculty director for a scholarship program to recruit and support high-performing, low-income civil engineering students. Dr. Watson is also interested in understanding and assessing students' cognitive processes, especially development of cognitive flexibility and interactions with cognitive load. Dr. Watson is the proud recipient of seven teaching awards and six best paper awards. She was previously named the Young Civil Engineer of the Year by the South Carolina Section of ASCE and currently serves as a Senior Associate Editor for the Journal of Civil Engineering Education.

Dr. Simon Thomas Ghanat P.E., The Citadel

Dr. Simon Ghanat is an Associate Professor of Civil and Environmental Engineering at The Citadel (Charleston, S.C.). He received his Ph.D., M.S., and B.S. degrees in Civil and Environmental Engineering from Arizona State University. His research interests are in Engineering Education and Geotechnical Earthquake Engineering. He previously taught at Bucknell University and Arizona State University.

Exploring Math Self-Efficacy Among First-Year Civil Engineering Majors

Introduction

Across the country, engineering retention rates are often low (approximately 50%) and highly correlated with calculus performance [e.g., 1, 2]. In fact, some authors assert that the biggest factor contributing to the attrition of first-year engineering students is inadequate mathematics performance [3]. As such, early calculus courses are often considered to be barrier courses, due to several issues, including perceived rigor [3], poor math preparedness [4], lecture-based teaching methods [5], and lack of engineering context [1]. For students, poor calculus performance can contribute to low grade point averages, disqualification from scholarships, poor academic standing, and consequently a desire to leave engineering or college all together [1]. The underlying cause of poor performance in college math courses may be more complicated than just lack of preparedness or ability. Rather, low math self-efficacy may be an important contributing factor to poor performance [6-8].

Self-efficacy is one's own personal judgements about their abilities to achieve specific goals [9]. According to Bandura's Self Efficacy Framework [10], 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. Literature supports that *mastery experiences* are the most important sources of self-efficacy information [e.g., 11]. Furthermore, self-efficacy is expected to lead to increased motivation and persistence when faced with adversity [12].

Math self-efficacy refers to an individual's beliefs about understanding math concepts and solving related problems [8]. Among college students, past math performance is thought to inform self-efficacy. In turn, future achievement is dependent on how students perceive their past performances [6]. Literature on differences in math self-efficacy by gender are mixed, with some authors finding higher self-efficacy among males and some finding similar self-efficacy among males and females [7, 8]. Studies examining development and impacts of math self-efficacy for engineering students are somewhat sparse, although some authors report that feelings about math are an important component of general engineering self-efficacy [13-16], including for females [17, 18].

The Mathematics Self-Efficacy and Anxiety Questionnaire (MSEAQ) is one instrument for measuring math self-efficacy. The MSEAQ was developed based on a general expectancy-value model using items resulting from a comprehensive literature review. The reliability and validity of the MSEAQ were rigorously examined through correlational analysis with similar scales, pilot tests in college Precalculus courses, and exploratory factor analysis. Five dimensions of math self-efficacy emerged from the analysis and were verified through student interviews: General Mathematics Self-Efficacy, Grade Anxiety, Future, In-Class, and Assignments [8].

The goal of our study is to explore how math self-efficacy develops among civil engineering students and how that self-efficacy might drive their will to succeed as engineering students. Specifically, we will address the following questions: (1) To what extent, if any, does math self-efficacy evolve over students' first academic semester? (2) How does math self-efficacy vary based on students' high school and college math experiences? (3) To what extent might math self-efficacy be associated with persistence in engineering? We hope to provide insights for how self-efficacy building can be used to encourage retention of diverse engineering students.

Study Methods

Participants: We conducted an observational study to explore the math self-efficacy of civil engineering freshmen at a regional, military college in the Southeast. We invited students enrolled in an Introduction to Civil Engineering Course to participate in our study. Of the 71 students enrolled, we collected data for 60 matched pairs (84.5% response rate). Of the matched pairs, 8.3% (n =5) identified as female, while all others identified as male.

Data Collection: We administered a paper version of the MSEAQ. Students responded to 28 items using a five-point, Likert-type scale to report on their thoughts and feelings about math courses. For each item, students could select an option of "no response." Cronbach's alpha for pre- and pos-assessments was 0.937 and 0.945, respectively. On the pre-assessment, we also asked students: "What was the highest math course you took in high school?" We collected additional data on each participant from institutional records, including: (1) first college math course, (2) grade in the course, and (3) retention status after their sophomore year.

Data Analysis: First, we used MSEAQ responses to calculate a normalized math self-efficacy score for each student at each survey administration time. We reverse-coded all items that expressed negative self-efficacy and summed responses by student (TOT). Next, we summed "no responses" by student (NR). We calculated the normalized self-efficacy score as: $TOT/[(28–NR) \times 5] \times 100$. Second, we binned and coded data on students' math experiences. For highest math course completed in high school, we created four groups: less than Precalculus, Precalculus, Calculus I, above Calculus 1. For first college math course, we created three groups: Precalculus, Calculus I, above Calculus I. We binned students' grades in their first college math course into two groups: A/B/C, D/F/W.

We conducted several two-way mixed Analysis of Variances (ANOVAs) in IBM SPSS 26 to explore relationships between math experiences, math self-efficacy, and engineering retention. For each mixed ANOVA, the within-subjects factor was time (pre- and post- math self-efficacy scores). The between-subjects factor was either gender, highest high school math course, first college math course, first college math grade, or retention. Significant interactions and/or main effects were identified at a significance level of $p \leq 0.05$. Required assumptions were verified, including [19]: (1) There were no outliers, as assessed by examination of studentized residuals for values greater than ±3; (2) Normalized self-efficacy scores were normally distributed, as assessed by Normal Q-Q Plots; (3) There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > 0.05$); and (4) There was homogeneity of covariances, as assessed by Box's test of equality of covariance matrices ($p > 0.05$).

Results

Self-Efficacy and Gender: Math self-efficacy increased more for females, as compared to males, over their first academic semester. Indeed, we found a statistically significant interaction between gender and survey administration time on math self-efficacy, $F(1, 58) = 4.64$, $p = 0.035$, partial $\eta^2 = 0.074$. Overall, normalized math self-efficacy scores increased more for females (65.3 ± 4.9 to 71.7 ± 5.2), as compared to males (68.9 ± 1.5 to 66.9 ± 1.6).

Self-Efficacy and High School Math Experience: Math self-efficacy was lowest for students who did not complete at least Precalculus in high school. We found the main effect of highest math course completed to show a statistically significant difference in self-efficacy between groups, $F(3, 55) = 5.00$, $p = 0.040$, partial $\eta^2 = 0.214$. Completing less than Precalculus in high school was associated with a mean math self-efficacy score of 25.2 (95% CI, -44.0 to -6.4) points lower than completing above Calculus I, a statistically significant difference, $p = 0.004$. In addition, completing Precalculus in high school was associated with a mean math self-efficacy score of 19.9 (95% CI, -38.4 to -1.4) points lower than completing above Calculus I, a statistically significant difference, $p = 0.030$. We found no interaction between highest high school math course and survey administration time, $F(1, 55) = 0.453$, $p = 0.716$, partial $\eta^2 = 0.024$.

Self-Efficacy and First-Semester College Math Experience: Math self-efficacy was lowest for students who performed poorly in, or did not complete, their first college math course. We found the main effect of first math grade to show a statistically significant difference in self-efficacy between groups $F(1, 58) = 6.26$, $p = 0.015$, partial $\eta^2 = 0.097$. Receiving a D/F/W in the first college math course was associated with mean math self-efficacy score of 6.5 (95% CI, -7.0 to -6.0) points lower than earning a "C" or higher. We found no interaction between first college math grade and survey administration time, $F(1, 58) = 0.877$, $p = 0.353$, partial $\eta^2 = 0.015$. In contrast, the first college math course itself, whether it be Precalculus or above, did not impact math self-efficacy. We found the main effect of first college math course to show no significant difference in self-efficacy between groups $F(1, 57) = 1.96$, $p = 0.151$, partial $\eta^2 = 0.064$. We found no interaction between first college math course and survey administration time, $F(1, 57) = 1.234$, $p = 0.299$, partial $\eta^2 = 0.041$.

Self-Efficacy and Retention: Math self-efficacy scores were lowest for students who eventually left engineering. We found the main effect of retention to show a statistically significant difference in self-efficacy between the two groups $F(1, 58) = 19.21$, $p < 0.0005$, partial $\eta^2 = 0.249$. Not persisting in engineering was associated with a mean math self-efficacy score of 10.8 (95% CI, -11.9 to -9.8) points lower than persisting in engineering. We found no interaction between retention and survey administration time, $F(1, 58) = 0.943$, $p = 0.336$, partial $\eta^2 = 0.016$.

Discussion

To what extent, if any, does math self-efficacy evolve over students' first academic semester?

The only group who showed a change in math self-efficacy over their first semester was female students ($\Delta = 6.4$, $n = 5$), as compared to male students ($\Delta = -2.0$, $n = 55$). While the sample of females is small, it represents 83% of all female freshmen civil engineering students from the population. All five female students showed higher math self-efficacy (although to different degrees) after completing their first academic semester. Furthermore, four of the five females (80%) were retained in engineering. As has been proposed by other authors [17, 18], the role of math self-efficacy in retention of female students may be especially important.

We also found it interesting that there was no change in math self-efficacy over the first academic semester when students were grouped by the grade earned in their first math course. Because mastery experiences (such as performing well in a course) are thought to be the most significant sources of self-efficacy [e.g., 11], we expected to see an increase in self-efficacy among high performers and a decrease among low performers. When we followed students through their sophomore year, 16 of 26 (62%) students who received a D/F/W in their first math class eventually left engineering, as compared to 5 of 34 (15%) students who received a "C" or higher. Possibly, changes in self-efficacy might be robust against short-term academic performance. If so, then specialized interventions targeted toward students with poor initial math performance might be especially important to resolve deficiencies before attrition occurs.

How does math self-efficacy vary based on students' high school and college math experiences?

We found that students' self-efficacy varied based on several aspects of their high school and college math experiences (although per RQ #1 there were no changes over their first semester based on these factors). As we expected, students' math self-efficacy was lowest for students who took less than Precalculus in high school (e.g., Algebra I-III, Statistics) and highest for students who completed above Calculus I (e.g., AP Calculus BC). Interestingly, there was no difference in self-efficacy between students who took up to Precalculus or Calculus I in high school. As such, pre-college advisors may be justified in recommending that prospective engineers take at least Precalculus, even if it is not required for high school completion.

Also, we found that self-efficacy varied with first college math grade, though not first college math course. Students who earned a C or higher in their first math course showed higher self-efficacy than those who earned below a C or withdrew. Even still, this trend held regardless of the math course that students first completed in college, whether it was Precalculus or higher. In terms of retention, rates were similar between Precalculus (29 of 45 retained, 64%) and Calculus (8 of 13, 62%). As previously discussed, the retention rate among those who earned at least a "C" in their first math course was four times higher than those who earned less than a "C" or withdrew. Consequently, it may be especially important to ensure that students enroll in a math course that aligns with their current skill set, even if they must devise an alternative plan to meet future prerequisite requirements. Among our population, and others [20], math self-efficacy was more dependent on grade earned, rather than course enrolled.

To what extent might math self-efficacy be associated with persistence in engineering?

We indeed found that math self-efficacy was highest among students who were retained through their sophomore year. Given the potential role of math self-efficacy in retention, it may be important to encourage classroom environments and support activities that help to build math self-efficacy, especially among students who do not complete Precalculus in high school and/or do not earn a "C" or higher in their first college math course. While poor performance in the first semester does not immediately deteriorate math self-efficacy, our data supports that a high proportion of these students eventually leave engineering. In contrast, we found that the first semester may especially influence the math self-efficacy of female students. In our case, female students performed quite well in their first college math courses, their self-efficacy improved, and nearly all were retained. While our findings are specific for our population, we expect some of the same trends in math self-efficacy could be observed among other student groups.

Conclusions & Future Work

An observational study was conducted to explore the sources and impacts of math self-efficacy among civil engineering students at a regional military college. During their freshmen year, students completed the MSEAQ at the beginning and end of their first semester. Data on math experiences was collected via survey and through official records. Retention was assessed at the end of students' sophomore year. The following conclusions were made based on the results.

1. Over the first semester, math self-efficacy changed only among female students. Females generally performed well in their first math course, experienced an increase in math self-efficacy, and were retained in engineering.
2. Students' who did not complete at least Precalculus in high school showed the lowest math self-efficacy during their freshmen year, while there was no difference in math self-efficacy between those who took Precalculus versus Calculus I. As such, Precalculus experience in high school may be especially important for success in engineering.
3. Math self-efficacy was highest for those students who earned at least a "C" in their first college math course, regardless of which course they enrolled in. As such, it may be important that degree plans allow for flexible, individualized math completion options.
4. Students who were retained in engineering after their sophomore year showed higher math self-efficacy during their freshmen year. Consequently, freshmen courses and support activities designed to build math self-efficacy may contribute to improved retention.

We are administering a cohort-based freshmen experience designed to build math self-efficacy among civil engineering students. Efforts center around encouraging *mastery experiences* through a novel first-year Calculus experience; supporting *vicarious experiences* through peer- and professional-mentoring programs; and managing *social persuasions* and *physiological arousal* through connection with an instructional strategist and mentors. We will continue to collect and analyze math self-efficacy data to better support our student population and assess the impacts of our freshmen cohorts. Ultimately, math-self efficacy likely varies between different groups and influences a student's decision to persist in or leave engineering; therefore, strategies to build self-efficacy may prove to encourage persistence of diverse groups in engineering.

Acknowledgement

This material is based upon work supported by the National Science Foundation (NSF) under Grant No. 1741611: Encouraging Civil Engineering Retention through Community and Self-Efficacy Building. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

References

[1] A. Baisley and V.D. Adams, "The Influences of Calculus I on Engineering Student Persistence," *ASEE Annual Conference and Exposition*, Tampa, FL, 2019. Avaialable: https://peer.asee.org/33386.

[2] N. W. Klingbeil and A. Bourne, "A National Model for Engineering Mathematics Education: Longitudinal Impact at Wright State University," *ASEE Annual Conference and Exposition*, Atlanta, GA, 2013. Available: https://peer.asee.org/19090.

[3] R. Suresh, "The relationship between barrier courses and persistence in engineering," *Journal of College Student Retention: Research, Theory & Practice,* vol. 8, no. 2, pp. 215-239, 2006.

[4] N. Langhoff and J. N. Le, "Development of a Cohort-Based Program to Strengthen Retention and Engagement of Underrepresented Community College Engineering and Computer Science Students," *ASEE Annual Conference & Exposition*, Salt Lake City, UT, 2018. Available: https://peer.asee.org/30320.

[5] M. K. Watson, S. T. Ghanat, T. A. Wood, W. J. Davis, and K. C. Bower, "A Systematic Review of Models for Calculus Course Innovations," *ASEE Annual Conference & Exposition*, Tampa, FL, 2019. Available: https://peer.asee.org/32007.

[6] G. Hackett and N. E. Betz, "An Exploration of the Mathematics Self-efficacy/Mathematics Performance Correspondence," *Journal for Research in Mathematics Education,* vol. 20, no. 3, pp. 261-273, 1989.

[7] M. Hall and M. Ponton, "A Comparative Analysis of Mathematics Self-Efficacy of Developmental and Non-Developmental Freshman Mathematics Students," *Meeting of Louisiana/Mississippi Section of the Mathematics Association of America*, Natchitoches, LA, 2002.

[8] D. K. May, "Mathematics Self-Efficacy and Anxiety Questionnaire," *Unpublished doctoral dissertation, University of Georgia,* Athens, GA*,* 2009.

[9] T. Yildirim, M. Besterfield-Sacre, and L. Shuman, "Scale Development for Engineering Modeling Self Efficacy," *ASEE Annual Conference & Exposition*, Louisville, KY, 2010. Available: https://peer.asee.org/16033.

[10] A. Bandura, "Self-Efficacy: Toward a Unifying Theory of Behavioral Change," *Psychological Review,* vol. 84, no. 2, p. 191, 1977.

[11] M. Sherer, J. E. Maddux, B. Mercandante, S. Prentice-Dunn, B. Jacobs, and R. W. Rogers, "The Self-Efficacy Scale: Construction and Validation," *Psychological Reports,* vol. 51, no. 2, pp. 663-671, 1982.

[12] A. Bandura, W. H. Freeman, and R. Lightsey, "Self-Efficacy: The Exercise of Control," Springer, 1999.

[13] E. L. Usher, N. A. Mamaril, C. Li, D. R. Economy, and M. S. Kennedy, "Sources of Self-Efficacy in Undergraduate Engineering," *ASEE Annual Conference & Exposition*, Seattle, WA, 2015. Available: https://peer.asee.org/24723.

[14] O. Eris, D. Chachra, H.L. Chen, S. Sheppard, L. Ludlow, C. Rosca, T. Bailey, and G. Toye, "Outcomes of a Longitudinal Administration of the Persistence in Engineering Survey," *Journal of Engineering Education,* vol. 99, no. 4, pp. 371-395, 2010.

[15] R. M. Marra, K. A. Rodgers, D. Shen, and B. Bogue, "Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy," *Journal of Engineering Education,* vol. 98, no. 1, pp. 27-38, 2009.

[16] M. A. Hutchison-Green, D. K. Follman, and G. M. Bodner, "Providing a voice: Qualitative Investigation of the Impact of a First-Year Engineering Experience on Students' Efficacy Beliefs," *Journal of Engineering Education,* vol. 97, no. 2, pp. 177-190, 2008.

[17] S. G. Brainard and L. Carlin, "A Longitudinal Study of Undergraduate Women in Engineering and Science," *Frontiers in Education Conference,* 1997, vol. 1, pp. 134-143.

[18] J. Concannon and L. H. Barrow, "A Cross-Sectional Study of Engineering Self-Efficacy," *ASEE Annual Conference & Exposition*, Pittsburgh, PA, 2008. Available: https://peer.asee.org/3144.

[19] Laerd Statistics. "Two-way mixed ANOVA using SPSS Statistics." Available: https://statistics.laerd.com (accessed 10 May, 2020).

[20] J. Gardner, P. Pyke, M. Belcheir, and C. Schrader, "Testing Our Assumptions: Mathematics Preparation and Its Role in Engineering Student Success," *ASEE Annual Conference & Exposition*, Honolulu, HI, 2007. Available: https://peer.asee.org/2314.