Integrating Robotics and Engineering Education: Initial Validation Testing of an SCCT- and CT-Based Survey Instrument (WIP)

Jialing Wu, The Ohio State University

Jialing Wu is a second-year PhD student in Engineering Education at the Ohio State University. She earned her M.Ed. in International Education Policy and Management at Vanderbilt University, Peabody College, and also holds a bachelor's degree in Mechanical Engineering from China. Her research interests encompass international engineering education, pre-college engineering and computational social science, applying quantitative methods and advanced technology in Engineering Education Research (EER).

Dr. Adam R Carberry, The Ohio State University

Dr. Adam R. Carberry is Professor and Chair in the Department of Engineering Education at The Ohio State University (OSU). He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. He recently joined OSU after having served as an Associate Professor in The Polytechnic School within Arizona State University's Fulton Schools of Engineering (FSE) where he was the Graduate Program Chair for the Engineering Education Systems & Design (EESD) Ph.D. Program. He is currently a Deputy Editor for the Journal of Engineering Education and co-maintains the Engineering Education Community Resource wiki. Additional career highlights include serving as Chair of the Research in Engineering Education Network (REEN), visiting École Nationale Supérieure des Mines in Rabat, Morocco as a Fulbright Specialist, receiving an FSE Top 5% Teaching Award, receiving an ASEE Educational Research and Methods Division Apprentice Faculty Award, receiving a Frontiers in Education New Faculty Award, and being named an ASEE Fellow.

Integrating Robotics and Engineering Education: Initial Validation Testing of an SCCT- and CT-Based Survey Instrument (WIP)

Abstract

Purpose: This work-in-progress study is an evidence-based practice paper that aims to provide initial validity evidence for an adapted survey instrument used in secondary-level robotics-based engineering education. The instrument includes 10 constructs comprising a total of 50 items. This paper specifically focuses on examining the validity of a robotics-based engineering self-efficacy construct.

Background: The e4usa+FIRST initiative is designed to enhance high school students' engineering learning through project-based robotics instruction, integrating hands-on design, programming, and problem-solving experiences. Previous studies have examined robotics and engineering education separately, while research examining their integration (e.g., using robotics projects as a vehicle for engineering learning) remains limited. To evaluate the impact of such integrated instruction, we developed a new survey instrument grounded in Social Cognitive Career Theory (SCCT) and the Computational Thinking (CT) framework to measure students' engineering design experience and CT-related skills.

Methods: Pre-survey data were collected from 81 high school students across seven participating schools during the 2025-2026 academic year. Students completed an eight-item self-efficacy scale using a 4-point Likert response format. Validity and reliability analyses included descriptive statistics, the Kaiser-Meyer-Olkin (KMO) measure, Bartlett's Test of Sphericity, exploratory factor analysis (EFA) using Principal Axis Factoring, and internal consistency reliability estimation using Cronbach's alpha.

Results: Descriptive results indicated moderate levels of confidence in robotics-based engineering design, with acceptable distributional properties. Factorability tests supported the use of factor analysis (KMO = 0.845; Bartlett's test $p < 0.001$). EFA results supported a single-factor structure, with all factor loadings exceeding 0.47. The scale demonstrated strong internal consistency ($\alpha = 0.85$), providing preliminary evidence of convergent validity and reliability.

Next Steps: Future work will further validate the instrument by examining expected relationships among SCCT and CT constructs and testing the stability of the factor structure in larger and more diverse samples, supporting its use in impact-focused robotics-integrated engineering education research.

Introduction

Robotics education has been shown to foster positive STEM attitudes while strengthening students' computational thinking [1]-[4], while pre-college engineering education has been shown to increase students' self-efficacy and interest in engineering [5], [6]. Combining robotics with pre-college engineering education suggests the potential to more effectively support students' preparation for and pathways into future engineering study and careers. Prior research has integrated robotics into engineering education to examine how it influences students' interest in engineering [7], [8], engineering students' computational thinking [9], and engineering design tasks [10]. Most existing implementations are short in duration [7], and few studies have conducted rigorous quantitative and qualitative evaluations[11]. This gap calls for the design of longer-term, robotics-integrated engineering courses and systematic research to examine impacts.

This research is grounded in e4usa+FIRST, a pre-college engineering education initiative aimed at expanding access to robotics-based engineering learning nationwide. Flexible robotics lessons have been developed for use as a stand-alone curriculum or supplemental content in high school-level STEM courses. Additional aspects of the project are intended to support teacher professional development, while advancing research on scalable and equitable engineering education. Through partnerships with Engineering for US All (e4usa) and For Inspiration and Recognition of Science and Technology (FIRST), the initiative engages diverse urban, suburban, and rural contexts by positioning teachers as co-creators, leveraging industry collaboration, and using iterative curriculum design and professional learning communities to strengthen STEM literacy and prepare a more diverse future engineering workforce [12].

This work-in-progress study aims to provide initial validity evidence for an adapted survey instrument used in high-school-level robotics-based engineering education. The instrument is grounded in Social Cognitive Career Theory (SCCT) and the Computational Thinking (CT) framework. SCCT explains how self-efficacy, outcome expectations, and goals jointly shape individuals' academic and career interests and choices [13]. CT refers to a problem-solving framework that involves abstraction, decomposition, and algorithmic reasoning to formulate solutions [14]. The full adapted survey includes 10 constructs comprising 50 items. This study focuses on validating the robotics-based engineering self-efficacy construct consisting of 8 items.

Methods

Data Collection

The study sample consisted of students from seven schools involved in the project during the 2025–2026 academic year. Pre-survey data were collected in September and October 2025, at the start of project involvement. A total of 81 valid responses were obtained. The survey protocol was approved by The Ohio State University Institutional Review Board (IRB). All students were informed prior to participation and provided consent or assent with parental consent.

Self-reported gender distributions indicated that 54 respondents identified as male (66.7%), 23 as female (28.4%), and four did not report gender. The sample was racially and ethnically diverse. As shown in Table 1, White students comprised the largest group (30.9%), followed by multiracial (23.5%) and Asian (17.3%) students. Additional groups included Middle Eastern (14.8%), Black/African American (6.2%), and Hispanic/Latino (4.9%). Two respondents did not report racial or ethnic identity.

Table 1. Students' Demographics.

Race/ethnic	**Number of Students**	**Percentage**
White	25	30.9%
Multiracial	19	23.5%
Asian	14	17.3%
Middle Eastern	12	14.8%
Black / African American	5	6.2%
Hispanic / Latino	4	4.9%
Not Reported	2	2.5%
Sum	*81*	*100%*

Instrument Design

The survey instrument was developed by integrating SCCT and CT frameworks to examine the impact of the e4usa+FIRST curriculum on high school students' engineering competencies. All items were rated on a 4-point Likert scale ranging from 0 (no confidence) to 3 (complete confidence).

The SCCT component included five constructs, including confidence in robotics-based engineering design, outcome expectations, engineering/robotics interest, intention and commitment to future plans, and perceived support and barriers. This piece of the survey comprised 30 items in total. These items captured how learning experiences relate to students' confidence and intentions to pursue engineering pathways. The CT component consisted of five constructs, including creativity, algorithmic thinking, cooperativity, critical thinking, and problem solving. This piece of the survey comprised 20 items. These measures assessed students' abilities to decompose complex robotics problems, develop logical sequences, and apply analytical reasoning in engineering contexts. Sample survey items are provided in Appendix A.

This work-in-progress study focuses on examining the validity of the SCCT self-efficacy-related survey component, i.e., confidence in robotics-based engineering design. The survey instrument was adapted from a previously tested questionnaire measuring engineering self-efficacy among high school students [15]. Modifications were made to align the items with robotics-integrated engineering contexts. The 8-items comprising this portion of the survey were:

- Identify a design need that can be addressed with a robotics-based engineering solution
- Research a design need that can be addressed with a robotics-based engineering solution
- Develop robotics-based engineering solutions
- Select the best possible robotics-based engineering design
- Construct a robotics-based engineering prototype
- Evaluate and test a robotics-based engineering design
- Communicate a robotics-based engineering design
- Redesign a robotics-based engineering solution

Measurement

Statistical analyses followed four stages to evaluate the validity and reliability of the survey instrument. First, data were screened for missing values and distributional properties to assess assumptions for parametric analyses. Next, factorability was examined using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity to determine whether item correlations were sufficient for factor analysis [16]. A KMO value above 0.80 indicates adequate sampling, and a significant Bartlett's test ($p < 0.05$) confirms that the data are suitable for factor analysis [16]. Exploratory Factor Analysis (EFA) was then conducted using Principal Axis Factoring (PAF), with factor retention guided by the Kaiser criterion and inspection of the scree plot [17]. Factor loadings were reviewed to ensure meaningful contributions of items to their intended constructs; items with loadings below 0.40 were removed [18]. Finally, internal consistency reliability was assessed using Cronbach's alpha (α). Cronbach's alpha values at or above 0.70 are commonly viewed as acceptable, while values at or above 0.80 are regarded as particularly strong [17]. All analyses were conducted in Python using the *pandas* and *factor_analyzer* libraries.

Results

Descriptive statistics results showed that mean scores across the eight items ranged from 1.59 to 2.05, indicating moderate levels of confidence in robotics-based engineering design for the given sample of students. Skewness values were negative across all items, ranging from -0.60 to -0.05, indicating slight left-skewed distributions. Kurtosis values ranged from -0.59 to 0.50, suggesting no substantial deviation from normality. These results indicate that the items met the assumptions for subsequent parametric analyses. Missing data were minimal, with only one missing response observed for Item Construct a prototype. All other items had complete data. Table 2 presents the descriptive statistics for the confidence in robotics-based engineering design items.

Table 2. Descriptive Statistics for Confidence in Robotics-based Engineering Design Items

Item	Mean	SD	Skewness	Kurtosis
Identify a design need	1.77	0.73	-0.60	0.50
Research a design need	1.93	0.70	-0.12	-0.37
Develop solutions	1.69	0.80	-0.13	-0.41

Select the best design	1.65	0.82	-0.10	-0.49
Construct a prototype	1.75	0.86	-0.21	-0.59
Evaluate and test a design	2.05	0.77	-0.42	-0.31
Communicate a design	1.73	0.81	-0.05	-0.56
Redesign a solution	1.59	0.82	-0.10	-0.45

The KMO value was 0.845 (> 0.8), indicating a meritorious level of sampling adequacy. Bartlett's Test was statistically significant ($p < 0.001$), confirming that inter-item correlations were sufficient for factor extraction. The EFA result supported a single-factor structure for the adapted engineering self-efficacy scale. As shown in Table 3, all eight items had factor loadings ranging from 0.47 to 0.80 (> 0.4). These results indicate that all items loaded meaningfully on the intended latent construct, providing evidence of convergent validity for the adapted scale. Internal consistency reliability was high, with a Cronbach's α of 0.85 (> 0.8).

Table 3. Factor Loadings for the Confidence in Robotics-based Engineering Design Items

Item	**Factor Loading**
Identify a design need	0.80
Research a design need	0.47
Develop solutions	0.80
Select the best design	0.68
Construct a prototype	0.73
Evaluate and test a design	0.59
Communicate a design	0.74
Redesign a solution	0.75

Conclusion and Future Plan

This study provides initial evidence that the adapted robotics-based engineering self-efficacy scale is a reliable and conceptually coherent measure when used with secondary students. The findings support the instruments used in secondary-level robotics-integrated engineering education and lays the groundwork for future studies. Future work will extend the validation evidence of the survey instrument by examining additional sources of validity evidence. As data collection continues across participating schools, subsequent analyses will assess relationships between the robotics-based engineering self-efficacy construct and other SCCT- and CT-related constructs to evaluate theoretically expected patterns. Further studies will also examine the stability of the factor structure across larger and more diverse samples, supporting the use of the instrument in impact-focused research on robotics-integrated engineering education.

References

[1] N. Arís and L. Orcos, “Educational Robotics in the Stage of Secondary Education: Empirical Study on Motivation and STEM Skills,” *Educ. Sci.*, vol. 9, no. 2, p. 73, Jun. 2019, doi: 10.3390/educsci9020073.

[2] A. R. Bayanova, N. A. Orekhovskaya, N. L. Sokolova, E. F. Shaleeva, S. A. Knyazeva, and R. L. Budkevich, “Exploring the role of motivation in STEM education: A systematic review,” *Eurasia J. Math. Sci. Technol. Educ.*, vol. 19, no. 4, p. em2250, Apr. 2023, doi: 10.29333/ejmste/13086.

[3] J. Leonard *et al.*, “Using Robotics and Game Design to Enhance Children’s Self-Efficacy, STEM Attitudes, and Computational Thinking Skills,” *J. Sci. Educ. Technol.*, vol. 25, no. 6, pp. 860–876, Dec. 2016, doi: 10.1007/s10956-016-9628-2.

[4] S. Atmatzidou and S. Demetriadis, “Advancing students’ computational thinking skills through educational robotics: A study on age and gender relevant differences,” *Robot. Auton. Syst.*, vol. 75, pp. 661–670, Jan. 2016, doi: 10.1016/j.robot.2015.10.008.

[5] A. R. Carberry, M. Dalal, and O. Emiola, “Anchors associated with secondary school students’ engineering design experiences,” *Int. J. Eng. Educ.*, vol. 38, no. 6, pp. 1646–1655, 2022.

[6] J. Wu, M. Dalal, and A. R. Carberry, “Advancing Equity: Exploring the Experiences of Transgender and Gender Non-Conforming Students in a Pre-College Engineering Course (Work in progress),” in *Proc. 2025 ASEE Annu. Conf. Expo.*, Montreal, QC, Canada, Jun. 2025, doi: 10.18260/1-2--57577.

[7] M. T. Chew, S. Demidenko, C. Messom, and G. S. Gupta, “Robotics competitions in engineering education,” in *2009 4th International Conference on Autonomous Robots and Agents*, Feb. 2009, pp. 624–627, doi: 10.1109/ICARA.2000.4804032.

[8] E. McGrath, S. Lowes, M. McKay, J. Sayres, and P. Lin, “Robots underwater! Learning science, engineering and 21st century skills: The evolution of curricula, professional development and research in formal and informal contexts,” in *Robots in K-12 Education: A New Technology for Learning*, B. S. Barker, G. Nugent, N. Grandgenett, and V. I. Adamchuk, Eds. Hershey, PA, USA: IGI Global, 2012, pp. 141–167, doi: 10.4018/978-1-4666-0182-6.ch007.

[9] S. Hutamarn, S. Chookaew, C. Wongwatkit, S. Howimanporn, T. Tonggeod, and S. Panjan, "A STEM Robotics Workshop to Promote Computational Thinking Process of Pre-Engineering Students in Thailand: STEMRobot," in *Proc. 25th Int. Conf. Comput. Educ. (ICCE)*, Christchurch, New Zealand, Dec. 2017, pp. 514–522. [Online]. Available: https://library.apsce.net/index.php/ICCE/article/view/2123

[10] B. Zhong, J. Zheng, and Z. Zhan, “An exploration of combining virtual and physical robots in robotics education,” *Interact. Learn. Environ.*, vol. 31, no. 1, pp. 370–382, 2023, doi: 10.1080/10494820.2020.1786409.

[11] F. B. V. Benitti and N. Spolaôr, “How Have Robots Supported STEM Teaching?,” in *Robotics in STEM Education: Redesigning the Learning Experience*, M. S. Khine, Ed., Cham, Switzerland: Springer International Publishing, 2017, pp. 103–129, doi: 10.1007/978-3-319-57786-9_5.

[12] M. Dalal, A. Iqbal, and A. R. Carberry, “Blended Implementation of Existing Precollege Engineering Programs: Teacher Perspectives of Program Impact,” *IEEE Trans. Educ.*, vol. 67, no. 3, pp. 364–376, Jun. 2024, doi: 10.1109/TE.2023.3338610.

[13] R. W. Lent, S. D. Brown, and G. Hackett, “Toward a Unifying Social Cognitive Theory of Career and Academic Interest, Choice, and Performance,” *J. Vocat. Behav.*, vol. 45, no. 1, pp. 79–122, Aug. 1994, doi: 10.1006/jvbe.1994.1027.

[14] J. M. Wing, “Computational thinking,” *Commun. ACM*, vol. 49, no. 3, pp. 33–35, Mar. 2006, doi: 10.1145/1118178.1118215.

[15] E. Lee, M. Dalal, A. S. Jannini, M. J. Miller, and A. Carberry, “Exploring Sources of Engineering-Related Self-Efficacy in the Context of a Pre-College Engineering Design Curriculum,” *Stud. Eng. Educ.*, vol. 6, no. 2, Dec. 2025, doi: 10.21061/see.229.

[16] L. R. Fabrigar, D. T. Wegener, R. C. MacCallum, and E. J. Strahan, “Evaluating the use of exploratory factor analysis in psychological research,” *Psychol. Methods*, vol. 4, no. 3, pp. 272–299, 1999, doi: 10.1037/1082-989X.4.3.272.

[17] D. B. McCoach, R. K. Gable, and J. P. Madura, *Instrument Development in the Affective Domain: School and Corporate Applications*, 3rd ed. New York, NY, USA: Springer, 2013, doi: 10.1007/978-1-4614-7135-6.

[18] T. Hong, Ş. Purzer, and M. E. Cardella, “A psychometric re-evaluation of the design, engineering and technology (DET) survey,” *J. Eng. Educ.*, vol. 101, no. 1, pp. 7–33, Jan. 2012, doi: 10.1002/j.2168-9830.2011.tb00037.x.

Appendix A: Example Survey Items

Scale: 0 = no confidence; 1 = low confidence; 2 = high confidence; 3 = complete confidence

Confidence in engaging in robotics-based engineering design
Q1. identify a design need that can be addressed with a robotics-based engineering solution
Q2. research a design need that can be addressed with a robotics-based engineering solution
Q3. develop robotics-based engineering solutions

Outcome Expectations
Q1. I believe engineering work can be exciting.
Q2. I believe that others would respect me if I had an engineering job.
Q3. I believe my family would value me having an engineering job.

Engineering/Robotics Interest
Q1. I am interested in reading articles or books about engineering
Q2. I am interested in working on engineering projects
Q3. I am interested in working on engineering projects that involve robotics

Algorithmic thinking
Q1. I can quickly figure out the logic or steps needed to solve a programming task.
Q2. I am interested in how robots follow programmed instructions.
Q3. I understand instructions better when shown as code.

Cooperativity
Q1. I enjoy cooperatively working with others on robotic assignments (or projects).
Q2. I learn more on robotic tasks when I work in a group.
Q3. I believe cooperative learning helps me improve my own robot ideas.

Critical thinking
Q1. I am good at making clear, step-by-step plans to solve robotics problems.
Q2. I enjoy trying to solve complex, robotics problems.
Q3. I am willing to learn challenging concepts in robotics

Problem solving
Q1. I often have trouble working out a robotics problem in my mind.
Q2. I often have trouble knowing where to use variables in my code.3. I often struggle with knowing how to use variables in my code.