Measuring Secondary School Students' Engineering Identity and Engineering Habits of Mind in the Next Engineers Programs (Work in Progress)

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Abstract

This Work in Progress paper aims to develop reliable and valid tools for engineering educators and researchers to assess secondary school students' engineering identity and engineering habits of mind to support students' future engineering career goals. Although it is critical to prepare secondary school students to explore and build their identity in engineering, most research on engineering identity development and on expanding the engineering workforce focuses on postsecondary students in higher education. Our Next Engineers programs bridge this gap and focus on supporting younger students in seeing engineering as a potential career in their early educational experiences. In this paper, we describe the development of measures of engineering identity and engineering habits of mind that are appropriate for secondary school students. These measures are designed to assess the impact of the Next Engineers programs and to be applicable in a broader range of pre-college engineering learning contexts. We present the measure development process and report preliminary results from initial analyses.

Introduction

The development of engineering habits of mind (EHoM) and engineering identity has been consistently linked to students' decisions to pursue engineering and their persistence in engineering pathways [1], [2], [3]. However, much of the research examining how young people develop these dispositions has studied them separately and has focused primarily on postsecondary populations who have already been elected to pursue engineering [4]. More recent research suggests, however, that learning to 'think like an engineer' and 'see oneself as a potential engineer' can begin much earlier, as students engage in formal and informal experiences that shape their interest, ways of thinking, and perceptions of competence and recognition [5], [6]. Moreover, experiences that support early development of EHoM and engineering identity may be particularly influential for bringing young people onto engineering pathways [5], [7]. As a result, there is a need for developmentally appropriate frameworks and measurement tools that can capture young people's early and evolving relationships to engineering.

In response to this need, this Work in Progress paper describes the design and refinement of a survey instrument intended to measure secondary school students' engineering identity and EHoM. The instrument is used to examine identity- and habit-related outcomes among students participating in Next Engineers (NE) Engineering Academy, an out-of-school program funded by the General Electric Aerospace Foundation in 7 cities globally to support secondary students' exploration of engineering.

Conceptual and theoretical framing

This study draws on two complementary constructs central to engineering pathway development: EHoM and engineering identity. As students engage repeatedly in engineering design processes and problem-solving activities, they begin to develop beliefs about their ability to think like engineers (EHoM). These beliefs are expected to support students' perceptions of competence and willingness to engage in engineering tasks, even in the absence of advanced technical knowledge (engineering identity).

Engineering habits of mind (EHoM)

Habits of mind are commonly defined as dispositions toward intelligent behavior in situations where answers are not immediately apparent [8]. While habits of mind have been articulated across disciplines, engineering-specific formulations emphasize patterns of thinking that support design, iteration, and problem solving. Lucas and Hanson [3] identify six core engineering habits of mind: systems thinking, problem-finding, creative problem-solving, visualizing, adapting, and improving.

For secondary school students, EHoM are unlikely to be fully developed or consistently demonstrated, particularly prior to sustained exposure to engineering coursework or programs. At early stages of engineering pathway development, students' beliefs about their ability to engage in engineering ways of thinking may therefore be more developmentally appropriate to assess than demonstrated performance.

Accordingly, this study operationalizes EHoM as self-efficacy beliefs related to engaging in engineering thinking and practices. Self-efficacy reflects individuals' judgments of their capability to carry out specific actions [9]. Measuring EHoM as self-efficacy allows for the assessment of students' emerging readiness to engage in engineering habits, even before they have had extensive opportunities to enact them.

Engineering identity

Our work adapts Godwin's [1] framework of engineering identity, which comprises three interrelated components: interest, recognition, and performance/competence beliefs. Interest reflects students' desire to engage with engineering; recognition refers to whether students perceive that others (e.g., teachers, peers, family) see them as an engineering person; and performance/competence beliefs capture confidence in succeeding in engineering-related tasks. Prior research links these components to students' persistence in engineering and their ability to envision future engineering selves, particularly among first-year college students [2].

Although developed for postsecondary populations, this framework provides a coherent foundation for examining engineering identity development earlier in the educational pipeline. Secondary school students are typically in an exploratory phase with uneven recognition and limited exposure to authentic engineering experiences, requiring careful adaptation of item wording and interpretation to ensure developmental appropriateness.

Previous instrumentation

Existing instruments for measuring engineering identity and related dispositions have been primarily developed for postsecondary students, motivating the need for the present study. Godwin's engineering identity framework, which conceptualizes identity through interest, recognition, and performance/competence beliefs, has been validated with postsecondary populations but assumes levels of disciplinary exposure and social recognition that many secondary students have not yet experienced [1], [2]. EHoM lack a widely validated instrument at any level. Prevailing formulations tend to be articulated as conceptual frameworks rather than empirically validated constructs [11].

Research questions

Our work aims to provide the field with an appropriate, valid, and reliable instrument for measuring secondary students' engineering habits of mind and identity. Specifically, we answer the following research questions:

1) What factor structures best represent secondary school students' engineering identity and engineering habits of mind as measured by the Engineering Development Survey 2.0?
2) To what extent do the adapted engineering identity subscales (interest, recognition, and performance/competence) demonstrate acceptable reliability and construct validity among secondary school students?
3) To what extent do engineering habits of mind, operationalized as self-efficacy beliefs, demonstrate coherent factor structure and acceptable reliability for secondary school students with varied exposure to engineering?

Context

NE Engineering Academy serves secondary school students (ages 15–18) through a multi-year, out-of-school program designed to support exploration of engineering over time through sustained engagement in hands-on learning and career exposure. Programming includes engineering design challenges, career skill-building, and mentorship from GE engineers. Rather than assuming students enter with a clear commitment to engineering, the program is structured to help students build familiarity with engineering practices, develop confidence in engaging in engineering ways of thinking, and receive recognition as capable participants in engineering-related activities. These experiences are expected to support growth across two interrelated outcome domains: engineering habits of mind and engineering identity.

Method

Design

The survey instrument was developed through a multi-year, iterative process following established best practices for scale development [12]. We conducted two development cycles. In Cycle 1, items were generated from a comprehensive literature review and administered to secondary school students (n = 1,128) across five cities in four countries to evaluate psychometric properties. In Cycle 2, items were revised and expanded based on Cycle 1 results, followed by a pilot study to further assess the instrument's psychometric quality. Based on the pilot study results, an improved version of the survey (i.e., Engineering Development Survey 2.0) was established for larger-scale administration in future years.

Item development – First cycle

The *first cycle* of development focused on the initial item creation where our interdisciplinary team worked collaboratively to design the items aligned with Engineering Academy program goals.

Step 1: Identifying domains and creating items. We began with a comprehensive literature review on engineering identity (e.g., [13]) and EHoM (e.g., [14]), which informed the initial instrument development. The initial version included two items assessing engineering identity and 18 items assessing EHoM.

Step 2: Establishing content validity. Experts in engineering education and curriculum design reviewed the initial items to ensure their appropriateness for secondary school students and alignment with engineering learning contexts, thereby establishing content validity.

Step 3: Administering the survey. We administered the initial version of the survey to 1,128 students in four cities across three countries, including Johannesburg in South Africa, Greenville and Cincinnati in the United States, and Staffordshire in the United Kingdom.

Item and Scale development – Second cycle

The *second cycle* of development focused on our analyses of the data collected through the *first cycle* and how we redefined the constructs based on the NE theory of change and relevant literature.

Step 1: Extracting factors and identifying appropriate items. We conducted an exploratory factor analysis (EFA) using data from Cycle 1 to explore how the items of engineering identity and EHoM were related within each construct. EFA results were evaluated against established scale-development benchmarks: factor loadings $\geq .40$, at least three items per factor, and a minimum of 50% total variance explained (e.g., [15], [16], [17]). In addition, latent constructs were required to include at least three items to ensure adequate construct representation [18].

Results indicated that the two engineering identity items loaded as expected but were insufficient to support a robust latent construct as suggested by the best practices in scale development. Therefore, we realized that the development of additional items was needed. For EHoM, the EFA identified three factors; four items failed to load on any factor, and one item was cross loaded on multiple items, with the overall factor structure explaining only 39% of the variance. These findings deviated from the initial design assumptions and indicated the need for substantial revision of the EHoM instrument.

Step 2: Refining and creating items. Because neither instrument performed as expected in the initial analyses, we redefined both constructs and revised existing items and developed new items based on theory and empirical findings to improve psychometric quality. For engineering identity, we revised the instrument to assess three dimensions, including *recognition* (5 items), *performance/competence* (4 items), and *interest* (7 items), adapted from a validated engineering identity measure for college students [1] and modified to ensure appropriateness for secondary school contexts (e.g., revising item wording to reflect age-relevant learning experiences).

For EHoM, the original items were intended to assess engineering-related behaviors; however, because the survey targeted students who likely had not yet entered the NE program or experienced any engineering learning activities, we reconceptualized EHoM as students' perceived capability to engage in engineering-related activities in the future. Consistent with Bandura's [9] definition of self-efficacy, we revised existing items and developed new items to assess self-efficacy across five EHoM subscales: system *thinking* (4 items), *adapting* (4 items), *problem* identification (5 items), *visualizing* (5 items), and *improving* (5 items). All items were constructed following Bandura's [19] guidelines for self-efficacy measurement, including the use of a 10-point Likert-type scale to capture greater variance.

Step 3: Testing items with a pilot study. The new sets of items that measure engineering identity and EHoM were piloted with 123 students who were in the Engineering Academy program to examine how the items performed psychometrically. We conducted an EFA with the pilot data. Each factor was evaluated against the previous version to understand improvement. For example, the original version of the interest construct explained 38.36% of the variance but the pilot version with more items improved and explained 62.02% of the variance. All seven interest items loaded onto one factor and had loadings above 0.66.

Step 4: Calculating reliability. We calculated Cronbach's alpha for each subscale of engineering identity and found adequate internal reliability scores for *interest* (0.91). Lower scores were found for *recognition* (0.69) and *performance/competence* (0.64). In terms of EHoM, we found adequate internal reliability scores for all the subscales, including *system thinking* (0.81), *adapting* (0.75), *visualizing* (0.79), *improving* (0.84), and *problem identification* (0.89)

Step 5: Modifying items based on pilot data. Based on the pilot psychometric results, we removed poorly performing items and reduced survey length to ensure feasibility for secondary school students. For example, within the Interest subscale of engineering identity, items with relatively lower factor loadings were removed, even though all loadings were greater than .60. The final interest subscale retained four items to balance psychometric quality and a proper survey length for school-age respondents.

Preliminary results

Because this WIP paper focuses on the instrument development process, development-related results are reported in the Method section to document key design decisions and psychometric refinements. Through a two-cycle development process, the final engineering identity and EHoM scales were aligned with the NE theory of change and supported by both theory and empirical evidence. The final version of the engineering identity scale includes *three* interest items, *five* recognition items, and *four* performance/competence items. These three dimensions (i.e., interest, recognition, and performance/competence) align with the prior framework of engineering identity examined by Godwin [1]. In addition, the final version of the EHoM scale includes *three* systems thinking items, *three* adapting items, *three* problem identification items, *four* visualizing items, and *three* improving items. These dimensions (i.e., systems thinking, adapting, problem identification, and improving) correspond to prior research on engineering habits of mind [3]. Overall, the instruments were streamlined to shorter sets of items, improving efficiency and feasibility for large-scale administration while maintaining strong psychometric quality.

Future work and discussion

This study contributes to engineering education research by advancing the measurement of EHoM and engineering identity among secondary school students, constructs that are widely theorized but unevenly operationalized in pre-college contexts [3], [5], [6]. In particular, the development of an EHoM measure represents an important foundational step for the field. While EHoM are often referenced as critical dispositions for engaging in engineering thinking, they are rarely assessed empirically within programs serving adolescents [3]. By operationalizing EHoM as self-efficacy beliefs and systematically refining a corresponding survey instrument, this work provides an initial, developmentally appropriate approach to measuring a construct that has historically been difficult to capture. This contribution is intended not as a finalized measure, but as a foundation that future researchers and practitioners can continue to test, refine, and adapt across diverse engineering learning environments.

In addition, this work brings engineering identity and EHoM into analytic conversation within a single measurement framework. Although engineering identity is commonly measured, it is less often examined alongside the dispositions that shape how students think and act in engineering-related contexts. Integrating these constructs enables the study of how students' beliefs about engaging in engineering ways of thinking develop in concert with interest, recognition, and performance/competence beliefs. As larger datasets are collected, this approach will support more nuanced analyses of the relationships between specific habits of mind and engineering identity development over time.

As we move forward, we aim to improve the psychometric properties of these tools, particularly the lower reliability of recognition and performance/competence in the identity instrument. These lower values may reflect item wording issues or variability in students' interpretations across contexts, which we will address in future work. The next steps of this project include 1) administering the revised survey to a large student population internationally, 2) establishing further validity, and 3) using validated instruments to measure the impact of Engineering Academy. This instrument is intended not only for use within NE but also for broader application in programs that aim to support young people in developing the skills necessary to pursue engineering careers.

References

[1] A. Godwin, "The Development of a Measure of Engineering Identity," presented at the 2016 ASEE Annual Conference & Exposition, Jun. 2016. Accessed: Jan. 16, 2026. [Online]. Available: https://peer.asee.org/the-development-of-a-measure-of-engineering-identity

[2] A. Godwin and A. Kirn, "Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives," *J. Eng. Educ.*, vol. 109, no. 3, pp. 362–383, 2020, doi: 10.1002/jee.20324.

[3] B. Lucas and J. Hanson, "Thinking Like an Engineer: Using Engineering Habits of Mind and Signature Pedagogies to Redesign Engineering Education," *Int. J. Eng. Pedagogy IJEP*, vol. 6, no. 2, pp. 4–13, May 2016, doi: 10.3991/ijep.v6i2.5366.

[4] E. Q. Rosenzweig *et al.*, "Beyond STEM attrition: changing career plans within STEM fields in college is associated with lower motivation, certainty, and satisfaction about one's career," *Int. J. STEM Educ.*, vol. 11, no. 1, p. 15, Mar. 2024, doi: 10.1186/s40594-024-00475-6.

[5] R. Dou, Z. Hazari, K. Dabney, G. Sonnert, and P. Sadler, "Early informal STEM experiences and STEM identity: The importance of talking science," *Sci. Educ.*, vol. 103, no. 3, pp. 623–637, 2019, doi: 10.1002/sce.21499.

[6] R. Dou and H. Cian, "Constructing STEM identity: An expanded structural model for STEM identity research," *J. Res. Sci. Teach.*, vol. 59, no. 3, pp. 458–490, 2022, doi: 10.1002/tea.21734.

[7] J. R. Morelock, "A Systematic Literature Review of Engineering Identity: Definitions, Factors, and Interventions Affecting Development, and Means of Measurement," *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 1240–1262, 2017, doi: 10.1080/03043797.2017.1287664.

[8] "Costa, A. L., & Kallick, B. (2000). Integrating and Sustaining Habits of Mind. Melbourne, VIC Hawker Brownlow Education. - References - Scientific Research Publishing." Accessed: Jan. 16, 2026. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=1427235

[9] A. Bandura, "The Explanatory and Predictive Scope of Self-Efficacy Theory," *J. Soc. Clin. Psychol.*, vol. 4, no. 3, pp. 359–373, Sep. 1986, doi: 10.1521/jscp.1986.4.3.359.

[10] A. M. Lucas, P. J. McEwan, M. Ngware, and M. Oketch, "Improving Early-Grade Literacy in East Africa: Experimental Evidence from Kenya and Uganda," *J. Policy Anal. Manage.*, vol. 33, no. 4, pp. 950–976, 2014.

[11] J. Anderson, A. Costa, and B. Kallick, "Habits of Mind: A Journey of Continuous Growth".

[12] G. O. Boateng, T. B. Neilands, E. A. Frongillo, H. R. Melgar-Quiñonez, and S. L. Young, "Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer," *Front. Public Health*, vol. 6, Jun. 2018, doi: 10.3389/fpubh.2018.00149.

[13] "Chapter 3 : Identity as an Analytic Lens for Research in Education - James Paul Gee, 2000." Accessed: Jan. 16, 2026. [Online]. Available: https://journals.sagepub.com/doi/abs/10.3102/0091732X025001099?casa_token=Nv-e7r_Y_6wAAAAA:yAAwmm4YzeB7LvR-MDaEyszmdx2nGqLqJEs0yyQAWxoTu4DrKUjUqeO6tP_7uop0GYat4KwOd28

[14] A. Cuoco, E. Paul Goldenberg, and J. Mark, "Habits of mind: An organizing principle for mathematics curricula," *J. Math. Behav.*, vol. 15, no. 4, pp. 375–402, Dec. 1996, doi: 10.1016/S0732-3123(96)90023-1.

[15] "Hair, J., Black, W., Babin, B., Anderson, R., & Tatham, R. (2006). Multivariate Data Analysis (6th ed.). Upper Saddle River, NJ Pearson Prentice Hall. - References - Scientific Research Publishing." Accessed: Jan. 16, 2026. [Online]. Available: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1385913

[16] "Tabachnick, B. G., & Fidell, L. S. (2013). Using Multivariate Statistics (6th ed.). Boston, MA Pearson. - References - Scientific Research Publishing." Accessed: Jan. 16, 2026. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=1541229

[17] K. S. Taber, "The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education," *Res. Sci. Educ.*, vol. 48, no. 6, pp. 1273–1296, Dec. 2018, doi: 10.1007/s11165-016-9602-2.

[18] L. A. Clark and D. Watson, "Constructing validity: New developments in creating objective measuring instruments," *Psychol. Assess.*, vol. 31, no. 12, pp. 1412–1427, 2019, doi: 10.1037/pas0000626.

[19] "Bandura, A. (2006). Guide for Constructing Self-Efficacy Scales. In F. Pajares, & T. C. Urdan (Eds.), Self-Efficacy Beliefs of Adolescents (pp. 307-337). IAP Information Age Publishing. - References - Scientific Research Publishing." Accessed: Jan. 16, 2026. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=3769518