frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 18 June 2025
DOI 10.3389/feduc.2025.1538497

OPEN ACCESS

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RECEIVED 02 December 2024
ACCEPTED 28 May 2025
PUBLISHED 18 June 2025

CITATION
Schilling MR, Matusovich HM, Grohs JR, Paradise T and Carrico C (2025) Differentiating middle school students' conceptions of engineering from interests in engineering.
Front. Educ. 10:1538497.
doi: 10.3389/feduc.2025.1538497

Differentiating middle school students' conceptions of engineering from interests in engineering

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Introduction: Developing and deploying research tools that measure pre-college students' conceptions of engineering is challenging, and often surveys relying on measurements of interest and identity are used to understand students' goals related to engineering. The purpose of this study is to describe the creation of and preliminary findings from a survey in the context of long-term engagement with middle school students.

Methods: To identify underlying factors related to student conceptions of engineering, this study leveraged exploratory factor analysis (EFA) with survey data from 360 middle school students along with descriptive and inferential statistics to understand more about the relationship between conceptions and interest and identity.

Results: Results from the EFA revealed a total of five factors related to a range of students' conceptions of engineering and interest and identity for engineering. Descriptive and inferential statistics further iterated that conceptions of engineering are distinct from interest and identity, meaning that, in some instances, understanding what engineering is does not always lead to increased interest.

Discussion: This study emphasizes the need to differentiate discussions about interest and identity in engineering from conceptions of engineering through more nuanced analysis of data. This study also contributes promising survey items and measures that can be translated to different contexts and further explored to measure conceptions of engineering.

KEYWORDS

conceptions of engineering, engineering engagement, engineering interest, exploratory factor analysis, middle school

Introduction

Despite a push to increase pathways into engineering by incorporating engineering into middle school, and K-12 education more broadly (National Academies of Science, 2013), actually measuring students' understanding of, and interest in, pursuing engineering degrees and careers remains challenging. The challenges are multifaceted in that they not only include pragmatic challenges associated with gathering data from young people, but also include challenges associated with conceptualizing engineering in ways that are meaningful for students. To be meaningful for students, introductions to engineering need to be age-appropriate but also grounded in contexts that may be familiar to students. For example, messaging about engineering for high school students in an area rich with employment opportunities associated with the aerospace industry (e.g., Seattle or Northern Virginia) would be different for middle school students in a rural area rich with agriculture-related employment opportunities (e.g., Knight et al., 2020).

Broadening participation in fields such as engineering, which often requires a prerequisite-laden college degree for employment (Carrico and Matusovich, 2016), depends upon reconsidering inclusion from assets-based approaches and being mindful of the local community context (Martin and Wendell, 2021). Therefore, an overarching goal of our larger work is to help students see engineering in the local community around them to help them conceptualize engineering and see possible futures in engineering. To accomplish this, we need effective tools to measure students' conceptions of engineering. Knowing that career aspirations, interests, and identity are important factors in pathways to engineering for many students (e.g., Henderson et al., 2021; Robinson et al., 2023) we developed a survey instrument by adapting existing surveys about interest, identity, and aspirations and adding new constructs which seek to explore more nuance related to student notions of what engineering work is and who can do it.

Herein, we describe the creation and results of a survey originally created to assess changes in student's conceptions of engineering before and after engaging in engineering activities. These engineering activities were implemented in their middle school science classrooms and were designed to be relevant for students in Appalachian and rural areas of Virginia. These activities were part of Virginia Tech Partnering with Educators and Engiineers in Rural Schools (VT PEERS) funded by the National Science Foundation (NSF). Detailed descriptions of the program can be found in prior publications (Grohs et al., 2020). Although we started with existing measurement instruments, we found that they did not meet our program research or assessment needs and significant revision was needed. To design an instrument more aligned with our needs, we reviewed data from classroom observations to understand how engineering was actually being portrayed to students and reconsidered the key messages we wanted to convey to students. We used this information to curate a new survey combining items from existing instruments and items pertaining to the project context and goals to try to measure students' conceptions of engineering. This study uses an exploratory factor analysis approach to develop a preliminary understanding of the survey structure in conjunction with descriptive and inferential statistics to examine data collected from middle school students (about ages 11–14) before and after a series of engineering activities. We ask the following questions through analysis of data collected with our instrument:

> RQ1. What are the underlying factors of conceptions of engineering for middle school students?
>
> RQ2. How are conceptions of engineering different from measures of engineering identity and interest for middle school students?

Our results reveal that, though imperfect, the instrument we developed is a useful measure that could help researchers and others working in similar contexts understand nuance within conceptions of engineering and that conceptions are distinct from engineering identity or interest in engineering.

Background literature

People across different age groups, from PreK-12 (e.g., Hammack et al., 2015), undergraduates (e.g., Trotskovsky et al., 2013), and educators (Antink-Meyer and Meyer, 2016), hold misconceptions about what engineering is and what engineers do. Forming appropriate conceptions of engineering is further complicated by representations being commonly provided in universal ways rather than in ways that would be meaningful based on the lived experiences of different populations of people.

Pragmatic challenges with existing measures of engineering conceptions for middle schoolers

There are several pragmatic challenges in measuring middle school children's conceptions of engineering. First, gathering data from middle schoolers is time and labor intensive. Because young people can have difficulty articulating complex thoughts (Piaget, 1971), it is common to use multiple modes of data collection to examine their conceptions of engineering. Researchers frequently pair surveys with interviews, focus groups or the draw an engineer test (DAET) (Knight and Cunningham, 2004) or pair the DAET with interviews or focus groups (Capobianco et al., 2011). This is often because developmental limitations inhibit effective use of one mode. For example, the DAET asks students to create a representation of an engineer, or more specifically, of an engineer at work. However, interviews or focus groups are needed to further explain the drawings as students' drawing abilities may be limited. Additionally, recent critique of the DAET and its focus on drawing is that it can even be challenging for adults to draw meaningful pictures (Reinisch et al., 2017). Interviews themselves can also be challenging with students because children are different from adults in the way that they think, speak and interact with others and there are additional strategies needed, such as building trust, to keep interviews on track, solicit detailed responses and ensure researcher understanding of the responses (Gibson, 2012). Therefore, it is critical to invest in continual development of instruments that are easy to use with children to facilitate further research and assessment.

Second, middle schoolers are at a transitory time in development as they are becoming adolescents which impacts many things including future career plans (Eccles et al., 2003; Eccles and Wigfield, 2020; Midgley et al., 2002). Middle schoolers are moving from a stage of thinking and learning in more concrete ways to an ability to process the abstract (Piaget, 1971). Conceptually, engineering careers can be seen by middle schoolers as both concrete and abstract. For example, identifying engineers as fixers and builders are concrete ideas whereas identifying engineers as designers and creators is more abstract (Gillen et al., 2017). As part of developing abstract thinking (cognitive maturation), they are also beginning to reflect more on themselves and they are experiencing changes in relationships with people around them (Eccles et al., 2003; Eccles and Wigfield, 2020) as they are thinking about careers and future pathways.

While middle school is an important time to expose students to engineering career pathways and possibilities, the many transitions they are experiencing could pose challenges for interpreting static measures or even trajectories for static measures used over time. For example, surveys that measure interest or identification with engineering or other careers are capturing thoughts at a moment in time. While true of all surveys, this could be particularly problematic for measuring career-related interests and/or trajectories of middle school students. In fact, Hidi and Renninger (2006) describe a four-phased interest model where interest can be intense and situational before becoming (or not) a more internalized and sustained interest. Simple measures of interest could conflate the two. This is likely to be magnified when measuring interest of middle school students who are in such a transitory time.

Third, many of the existing surveys used with middle school students measure identification with or interest in engineering versus conceptions of engineering. As noted, the DAET measures students' conceptions of engineers/engineering work but they are labor intensive to administer and interpret. Surveys, though more succinct measures, do not often actually measure conceptions of engineering. Instead, they often measure interest in or some marked desire to pursue an engineering career, which may often be conflated with how students understand what engineering is (Pleasants and Olson, 2019). For example, the engineering identity development scale (Capobianco et al., 2012) is designed to measure identification with engineering. In another example, Harlan and Van Haneghan (2020) utilized the Assessing Men and Women in Engineering (AWE) project survey with middle school students to determine the latent factors in a survey that measures occupational values students held related to STEM careers. While perhaps interest in engineering is a reasonable proxy for conceptions of engineering in some cases, for middle schools there is considerable self- and career-discovery happening. In fact, our project started with the Engineering Identity Development Survey (EIDS; Capobianco et al., 2012) and found that it was not helpful in examining if, and how, we were impacting students' understanding of engineering or engineering career possibilities (Grohs et al., 2020).

What we know about students' conceptions of engineering

Starting from elementary school, it is well-known in existing literature that students have limited conceptions of what engineers do and who engineers are. Elementary students perceive that engineers are mechanics, laborers and technicians and that they fix, build and make things using vehicles, engines and tools (Capobianco et al., 2012; Cunningham and Lachapelle, 2014). When asked to identify activities that engineers would be involved in, from a list of prescribed activities, elementary students did not identify that engineers would design ways to clean water or read about inventions (Cunningham and Lachapelle, 2014). This aligns with the misconceptions that engineers only work with mechanical items (e.g., engines, tools, computers, etc.) and that most engineers produce physical, tangible products. Though focused on STEM more broadly through a lens about the work scientists do, Padwick et al. (2022) identified that students around the ages 4–11 demonstrated varying levels of understanding about what scientists do, ranging from more undeveloped understandings to more diversified and complex understandings.

Limited perceptions of engineering often carry through to middle school and beyond. In a survey given to 1701 middle school students, 49% of students expressed that they know what engineers do, while 18% did not know what engineers do and 33% were unsure if they knew what engineers do (Gibbons et al., 2004). Middle school students still perceive that engineers mostly build things and that they tend to work with mechanical products to produce physical products (Jordan and Snyder, 2013). While these perceptions are true of engineering and are helpful things for students to know about engineering, they are limited in scope and do not completely represent the field of engineering. It is also common for science teachers, the most common school subject for engineering integration, to have misconceptions of engineering and have a hard time distinguishing between science and engineering (Antink-Meyer and Meyer, 2016). Other researchers have suggested that family involvement in engineering activities for students can help with the development of student interest in engineering as well as mitigate some of the effects of misconceptions of engineering (Pattison et al., 2020).

Even though middle school students and teachers often have narrow conceptions of engineers and what engineers do, it has been shown that engineering initiatives can help broaden student conceptions and address misconceptions. For example, an engineering summer camp discussed in Hammack et al. (2015) improved aligned perceptions and interest in engineering for students. Additionally, an afterschool program discussed in Jordan and Snyder (2013) broadened student conceptions of engineering by connecting design activities with knowledge of engineering. Addressing these misconceptions and demonstrating what students need to do to pursue an engineering career path are crucial tasks, especially for middle school students (Blanchard et al., 2015). Overall, we know that middle school students often have limited conceptions of engineering which can lead them to hold misconceptions about what engineers do. Therefore, it is important to understand how conceptions of engineering might vary to better address how to expand students' views about engineering, along with activities that are related to fostering interest in engineering and identification with engineering. However, there are few methods and approaches to measure conceptions, interest in engineering and engineering identity, and, in fact, these three constructs are often conflated (Pleasants and Olson, 2019).

Conceptual framework

The primary framework informing this study is that of conceptions of engineering, informed by different scholars who have discussed epistemology, engineering literacies, and the nature of engineering, as well as theories from existing survey instruments related to engineering identity and interest. When engaging with students around engineering careers, we must convey what is meant by engineering and what it could mean to be an engineer. In doing so, we seek to help students understand the nature of engineering and help form their conceptions of engineering. Many efforts in K-12 have focused on introducing students to the structure of the engineering discipline, very few of these efforts have emphasized conceptions of engineering or the nature of engineering. As such, our conceptual framework is guided by existing literature about conceptions of engineering and nature of engineering to help us understand:

1) How engineering might be understood as a discipline and, in some instances, a career;
2) How we can connect conceptions of the engineering discipline and work to meaningful examples; and
3) How to understand differences between conceptions of engineering, engineering identity, and interest in engineering.

The following sections describe work pertaining to engineering epistemology, engineering literacies, the nature of engineering, as well as some information about the theories from existing survey instruments.

Engineering epistemology and dimensions of engineering

As a discipline and a field, there are several ways to think about what engineering is. A useful framework for this comes from de Figueiredo (2008), which includes the following four dimensions: engineer as sociologist, engineer as scientist, engineer as designer, engineer as doer. Each of these dimensions can be combined to think about what an engineer is and what an engineer does. These dimensions suggest that engineering requires interdisciplinary approaches spanning across science, mathematics, and sociology, for example (de Figueiredo, 2008; Purzer and Quintana-Cifuentes, 2019; Purzer et al., 2022). Purzer et al. (2022) further supports the idea that engineering spans disciplines and purposes through different practices and inquiries. Thinking about the epistemological underpinnings of engineering provides insight into what engineering is and what engineering work looks like based on different practices and purposes.

Engineering literacies

In addition to this framework, other researchers have proposed connections between engineering and literacies (Silvestri et al., 2021). Understanding the literacies of the discipline can also help students develop their conceptions of engineering. For example, in their literature, Silvestri et al. (2021) highlighted important forms of communication involved in engineering, including images and drawings, demonstrations, materials, and other documents that communicate ideas. Additionally, the integration of STEM concepts is a key component of engineering design, which is another disciplinary literacy of engineering. Silvestri et al. (2021) also noted that dealing with uncertainty and risk is an important part of engineering, as well as being able to work in team environments. Engineering literacies provides a framework for the skills required of engineers or those skills that engineers use regularly and further aides understanding of what engineering is.

Nature of engineering

Pleasants and Olson (2019) conducted a literature review to better define the nature of engineering, as it is something that is often not clearly defined or communicated but is related to how students conceive engineering. Pleasants and Olson (2019) identified nine features of engineering that can help frame the nature of engineering: design in engineering; specifications, constraints, and goals; sources of engineering knowledge; knowledge production in engineering; the scope of engineering; models of design processes; cultural embeddedness of engineering; the internal culture of engineering; and engineering and science. Notably, Pleasants and Olson (2019) differentiated the nature of engineering from perceptions of engineering, suggesting that perceptions include the stereotypes students hold of engineers, their ideas about the work engineers do, and whether students think engineering is valuable to society. Additionally, Pleasants and Olson (2019) note that in much research, the nature of engineering is conflated with students' attitudes towards engineering, often not differentiating between students' interest or self-efficacy in engineering and how students understand engineering. Thinking about the nature of engineering, as described by Pleasants and Olson (2019), helps us understand differences in engineering as a field, discipline, and/or practice and perceptions of engineering informed by sociocultural influences about engineering.

Existing survey instruments about interest and identity and current study

Using this grounding in conceptions of engineering, our conceptual framework is further strengthened by our approach to creating a research- and practice-informed survey instrument. The research-informed elements emerged from current literature as described above and specifically through the use of existing survey instruments related to identity and interest development, understanding in engineering, engineering identity, and overall STEM career interest (survey items attributed in Appendix A; e.g., Blanchard et al., 2015; Capobianco et al., 2012; Cunningham and Lachapelle, 2014; Hynes et al., 2021; Kier et al., 2014; Knight et al., 2017; and Michaelis and Nathan, 2015). The practice-informed element comes from our longitudinal work within a project designed to broaden students' conceptions of engineering and hopefully spark interest in engineering degrees and careers (Matusovich et al., 2017). We started with existing survey instruments and expanded our list of questions based on our evaluation of the functionality of the instrument as well as reflecting on our intentions in teaching students about engineering and how these intentions were manifested in actual middle school classrooms. The conceptual framework was primarily used to understand the results of this study and responses to items on the final survey instrument.

Materials and methods

The following sections detail the context in which this data was collected, how the survey instrument was developed through extensive classroom observations, and the analysis of the survey through exploratory factor analysis (EFA) and inferential statistics.

VT PEERS project context

The VT PEERS project, funded by the National Science Foundation (NSF), has been described in great detail elsewhere (Grohs et al., 2020) but we highlight elements salient to the survey development here. With a goal of building community capacity for integrating engineering into middle school science classrooms, VT PEERS partnered with school educators, local industry experts, and researchers in three rural school districts in or near the Appalachian region of the Commonwealth of Virginia to collectively develop and facilitate engineering-related curriculum. In year three of the VT PEERS project, lesson plans were collaboratively implemented across all three counties in a total of 112 class sessions between August 2019 and March 9, 2020 with 737 sixth grade students, 798 7th grade students, 618 8th grade students, 5 university engineering and technical field graduate student facilitators, and 14 volunteering industry professionals. Importantly, the curriculum was designed to meet science standards identified by educators as relevant and important places to infuse engineering such that the engineering curriculum fit within teaching expectations and did not add disconnected content to an already full school year. The curriculum was designed as a series of activities that introduced students to the idea that engineering is all around them and part of their daily lives. For example, one activity focused on designing and building roads in a mountainous region, much like the regions in which students live and attend school. The goal was to use ideas perceived to be meaningful in the context of these students' lived experiences.

Over the three years of the project, the team collected extensive data including interviews with education, industry and research partners, observations of the activities in the classrooms, and pre-post draw-an-engineer test (DAET), and surveys with students. We used the data to inform and evolve the activities, partnership development and support strategies. Of particular importance to this analysis are the classroom observations which helped us contextualize how our plans for introducing engineering to students unfolded.

Developing the survey instrument

At the start of the project, we chose the Engineering Identity Development Survey (EIDS; Capobianco et al., 2012) as one of our pre-post survey instruments to measure differences in student outcomes. Specifically, we thought introducing engineering in locally relevant ways by leveraging familiar contexts could be meaningful for students and increase students' interest in or identification with engineering. However, analysis from our first year of data (Grohs et al., 2020) revealed that the survey was insufficient for our needs. We discovered the "engineering career" construct contained items that seemed to measure what engineering is conceptually (e.g., "Engineers solve problems that help people") and constructs related to wanting to be an engineer, e.g., ("When I grow up I want to be an engineer"). While both are important to the desired outcomes of our study, we needed to find a way to separate and enhance both measures. Therefore, in year 2 of the study we added questions specifically related to motivation to support further understanding the construct of wanting to be an engineer. In year 3, we realized a need to better understand students' conceptions of engineering and used our observation data to help us understand what conceptions we might actually be promoting through our class activities. Based on year 1 results, we also adjusted our survey scale, moving from a three-point Likert scale (No, Not Sure, Yes) to five-point Likert scale (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree). Using a five-point Likert scale helps ensure the scale is at least interval, an assumption of parametric statistical tests (Field et al., 2012; Grohs et al., 2020).

Classroom observations

We collected extensive observation data across the three years of the project and each year our observation data were used to inform revisions to our data collection instruments and contextualize the results of the survey. In year one, we conducted 44 observations in sixth grade classrooms across three counties and attempted to observe every activity hosted by VT PEERS. In year two, we added seventh grade classrooms but switched to a sample plan of observations resulting in 35 total observations across both grades in the three counties. In year three, we added eighth grade classrooms and conducted a total of 66 observations in all grades across the three counties. Some details of the observations from year one and two are included below to provide context for the project, survey development, and results.

During year 1, observation notes suggested that the curriculum exposed students to engineering concepts or careers but perhaps not as consistently or coherently as we might have liked. Observation notes suggested specific comments had been made during the activities about engineering concepts such as the tasks they do: measuring, recording, testing, and retesting. Other observation notes addressed mentions of career work that engineers do, such as Civil Engineers mitigate damage on roads and bridges caused by weather or climate damage. Because our project intentionally partners with industry, other observation notes indicated general discussions of who an industry partner employs, but not necessarily specific to engineering or engineering requirements. Finally, the observation notes from several classroom sessions indicated a lack of specific discussion regarding engineering, but that the students were told they were being engineers that day and should use their creative engineering minds. Though this information was insightful especially when taken in context with other observation data, it demonstrated a potential misalignment between the purpose of the classroom activities and the motivation and identity constructs in the surveys and thus a need to consider how our lesson plans, industry participants, and others talked about engineering.

During year 2, we specifically asked observers to look for and describe instances of exposing students to engineering concepts and/or careers. A mix of observations resulted. Many of the comments contained concrete examples of engineering that had been discussed such as: engineers test materials, engineers ensure good quality, the products being made are used locally, or that engineers are problem solvers and "that's the focus of the day." A few examples were more abstract and made connections between the environment and engineering, such as releasing less pollution into local waterways. Furthermore, a few observations noted an abstract concept such as engineers "make the best decision you can based on limited data." Note that these observations continue to focus more on "tasks" engineers conduct at work and "what they make" and less about abstract concepts such as who they work with, how they work, or what motivates engineers. To address this, the research team developed a collection of "Things to Know" or TTK which identified important components of engineering that spanned across abstract and concrete. As a result, a purposeful addition of TTK was added to year 3 curricula and to the year 3 survey (Appendix A, items 13 through 21 reflect the TTK).

Data collection

Participants in this study consisted of middle school students (grades 6–8, about ages 11–14) in school districts in Southwest Virginia. The data used in the exploratory factor analysis of this study consists of the pre-survey data that was collected on Scantrons in Fall 2019 and post-survey data that was collected during late Fall 2019 and into Spring 2020. The pre-surveys were distributed to teachers who distributed them to students. 360 students across 6th, 7th and 8th grades who completed the pre-survey were included after parental consent and student assent were considered. Post-survey data was collected electronically from students, a decision made after learning students were more comfortable with the electronic format. However, due to significant disruptions in education from COVID-19, data was not able to be collected from all participating students, leaving only 99 participants with completed post-test surveys. These 360 pre surveys and 99 post surveys were considered in this analysis, and limitations of this discrepancy in sample size are noted. The data collected in this study received IRB approval from the authors' institution.

Demographic data collected from the pre-survey, which is the primary dataset for the exploratory factor analysis, broken down by grade can be seen in Table 1. Students were asked to report their gender using an open-ended question, which allows them to describe themselves. Though we recognize that sex and gender are terms that are not the same but often conflated, and that gender extends beyond the binary of man and woman, the language we used to report our data is reflective of the language participants used to describe themselves. The third category of "Other Gender or Not Reported" was combined to protect the participants in our study and includes the many cases in which students did not report gender. Students were not asked to report data related to race and ethnicity. However, each of the counties have a population that is about or greater than 90% white, compared to the rest of the state at 69% white (United States Census Bureau, 2021).

Data analysis

The primary method of data analysis used in this study was exploratory factor analysis (EFA) to determine the underlying factors and latent structure of the survey instrument (Fabrigar et al., 1999; McCoach et al., 2013). EFA is a method of data analysis that is used when there are no assumptions about pre-existing constructs. Though the survey was developed from prior work, it was not clear how the items would relate to each other prior to analysis since items were pulled from several different existing tools. Additionally, as described in prior sections, we added our own items to the survey based on our practice and as evidenced through our observations. In this EFA, all items were analyzed together using a direct oblique rotation, which allows factors to be correlated (Fabrigar et al., 1999). The RStudio software v 1.1.456 was the primary analysis tool and the *psych* package (Revelle, 2020) in particular provided the appropriate functions for analysis. Prior to analysis, missing data from the pre-survey dataset was imputed using multivariate imputation by chained equations (MICE) and the corresponding RStudio package mice (van Buuren and Groothuis-Oudshoorn, 2011). Data was only imputed for those participants that had less than 10% of their data missing which excluded 14 participants for a total of 346 participants. After data was imputed, an additional 19 participants were excluded based on being outliers determined by the Mahalanobis distance cutoff, leading to a final total of 327 participants.

TABLE 1 Demographic data collected from pre-surveys.

Grade	Gender		
	Girl/female	Boy/male	Other gender or not reported
6 (N = 134)	57	41	36
7 (N = 126)	64	53	9
8 (N = 100)	45	41	14

Additionally, post-EFA analysis was performed to examine differences in factor scores between groups of students using the non-parametric Kruskal-Wallis test. Friedman's ANOVA was performed to determine any pre- and post-survey differences within groups. The results presented for these statistical tests are primarily exploratory to understand more about participant responses.

Group positionality

All authors on this paper were involved in the VT PEERS project to varying levels ranging from graduate research assistants to PIs. All participants except for the first author had on-going experience and engagement with the VT PEERS project. All authors are in the field of engineering education, which influences our lens on how students might think about and engage with engineering concepts. Additionally, all authors are committed to or generally interested in seeing engineering be locally relevant to more rural Appalachian students, and this greatly influenced the way we approached survey development and data analysis.

Limitations

Like all studies, our study has limitations. First, several of our items (named Things to Know or TTK) are newly developed and would need refinement for future use and with other student populations. Second, our study sample was limited to a specific region and associated with a specific intervention, and as such may not be relevant for all interventions though we believe it would be transferable across contexts. Additionally, though the pre-survey sample size was adequate for EFA, the sample size for post-survey analysis was severely impacted by COVID-19 and as such, impacted the availability of data to use for confirmatory factor analysis (CFA) and other post-survey analysis, impacting possibilities of Type II errors. As such, findings should be interpreted through this lens. However, the preliminary findings from conducting EFA and preliminary pre- and post-survey analyses are useful and important for other researchers doing similar work to consider and build upon in future iterations.

Importantly, we also recognize that the conceptions discussed in our study are not necessarily representative of all conceptions of engineering or epistemologies. As such, we recognize that this can be considered a starting point and should be further expanded to include different epistemologies and related conceptions of engineering. For example, Indigenous epistemologies are not necessarily represented in this survey instrument and might be considered in future iterations.

Results

The results presented below consist of both the results from EFA and pre- and post-survey analysis.

Exploratory factor analysis

Assumptions of normality, homogeneity of variance, and homoscedasticity were all tested by first running a linear regression on the data and using the standardized residuals. The results of the Shapiro–Wilk test, $W = 0.97$, $p < 0.001$ suggest that the data is not normal however in conjunction with a Q-Q plot, the data were determined to be mostly normal (Field et al., 2012). Homogeneity of variance and homoscedasticity were checked using a plot of the standardized residuals versus the fitted residuals. The spread of the data was mostly around 0, indicating these assumptions were met. Additionally, a correlation matrix was used to check if any items were too highly correlated—in this case, there were no items that were highly correlated and therefore no items were removed at this stage of analysis. Finally, Bartlett's test suggested the correlations were at least large enough to continue with analysis, $\chi^2(496) = 5{,}092$, $p < 0.001$. The Kaiser-Meyer-Olkin (KMO) test suggests that the sample is adequate with an overall mean sampling adequacy of $MSA = 0.94$. These assumption checks and tests suggest that the exploratory factor analysis could be conducted.

Parallel analysis suggested that five factors should be used for this analysis (Fabrigar et al., 1999; Godwin, 2016). Checks were conducted using the suggestions from eigenvalues of three and four factors, though these were determined to make analysis redundant due to reasons such as too few items on a factor, or many items loading onto many factors such that eliminating the items would eliminate a factor. Three rounds of analysis using five factors were conducted. After the first two rounds, items were eliminated if they loaded onto multiple factors or loaded onto no factors, where 0.3 was used as the minimum loading (Fabrigar et al., 1999). After the third round of analysis, a total of five items were removed. Table 2 shows all the survey items and factor loadings, including details about the removed items. The root mean square of the residuals (RMSR) was 0.03. The Tucker Lewis Index was 0.957, the root mean square error of approximation (RMSEA) was 0.037, and the CFI value was 0.972. These measures of fit suggest that this is a good fit (Fabrigar et al., 1999; Godwin, 2016; Hu and Bentler, 1999). Cronbach's alpha, $\alpha = 0.916$, suggests that these results are reliable.

In summary, analysis revealed five factors associated with student's conceptions of engineering (Table 2). Three of them were associated with nuances in what engineering is: common conceptions of engineering, abstract conceptions of engineering, and specific conceptions. The other two related more to interest in and identification with engineering: future engineering pursuits and current engagement with engineering. These factors were named to be representative of the themes the items represented through discussions and review among the research team. Equally important are the items that did not load onto a single factor, which still contributed to our understanding of the survey and the program overall. Table 3 provides information about the survey items and factor loadings from the EFA process. Table 4 shows the correlation between factors, noting that the factors related to conceptions are more highly correlated to each other than they are to the non-conception factors. Table 5 shows the internal consistency of each factor as measured by Cronbach's α. Table 6 shows factor scores as applied to the imputed pre-test dataset to describe the spread of the responses for each factor and corresponding survey items.

TABLE 2 Overview of factors identified from EFA.

Category	Factors
Conceptions of engineering at various levels	Common conceptions of engineering
	Abstract conceptions of engineering
	Specific conceptions of engineering
Current and future engagements with engineering related to interest in and identification with	Future engineering pursuits
	Current engagement with engineering

Pre- and post-survey analysis

Once these factors were identified, further analysis was completed comparing groups and existing pre- and post-surveys. All consented participants ($N = 360$ for pre-test and $N = 99$ for post-test) were split into two groups: Group 1 being students in grade 6 who participated in less than one year of VT PEERS activities and Group 2 being students in grades 7 and 8 who participated in more than one year of VT PEERS activities. Assumptions of normality were not met, therefore, further analysis began with a Kruskal-Wallis test to compare responses between Groups 1 and 2 on the pre-test and the post-test. There were significant differences between Group 1 and 2 pre-test responses (Table 7), however there were no significant differences between Group 1 and 2 post-test responses. From this, 84 students were identified as having completed both a pre-test and a post-test. The data from these students who completed both pre- and post-test was used to perform Friedman's ANOVA, a non-parametric version of a repeated measures one-way ANOVA (Tables 8, 9).

Discussion

Addressing our first research question, the results of our analysis reveal that: (1) conceptions of engineering can be measured, and (2) there are nuances or layers that can be captured in these conceptions. Our study with middle school students revealed common conceptions, specific conceptions, and abstract conceptions of engineering (Figure 1). Addressing our second research question, our analysis demonstrated that conceptions of engineering are separate from what students are currently doing related to engineering and what they might do in the future. These findings are discussed in more detail in the following sections, and some additional discussion has also been included about the items that were removed from the survey as a result of the EFA process.

Layers of conceptions of engineering (RQ1)

There were three distinct factors that defined the conceptions that were salient to students in this study. The first salient factor to students dealt with more common conceptions of what engineers do. "Common" is used to describe this factor as the items are representative of things you might know about engineering without prior engagement, and the items are also somewhat vague and nondescriptive. For example, the items in this factor dealt with things like engineers making and learning from mistakes, working on "things," using math, figuring out how things work, designing things, and using tools. For example, it is reasonable to expect that students understand that engineers use math– this is related to the connections

TABLE 3 Survey items, factor names and factor loadings.

Item	Wording	F1: common conceptions of engineering	F2: future pursuits of engineering	F3: current engagement with engineering	F4: abstract conceptions of engineering	F5: specific conceptions of engineering
21	Engineers view mistakes as normal and try to learn from them.	0.47				
22	Engineers work on things.	0.91				
23	Engineers use math.	0.63				
24	Engineers figure out how things work.	0.7				
25	Engineers design things.	0.62				
30	Engineers use tools.	0.78				
1	I plan to use engineering in my future career.		0.79			
2	My parents would like it if I choose an engineering career.		0.53			
3	I am interested in careers that involve engineering.		0.7			
4	I like activities that involve engineering.		0.49			
5	I have a role model in an engineering career.		0.49			
7	I know of someone in my family who is an engineer.		0.3			
6	I would feel comfortable talking to people who are engineers.			0.49		
8	I work on engineering projects outside of school at least once a week.			0.44		
9	I try to learn more about engineering on my own if I find VT PEERS interesting.			0.56		
11	I think everyone should know a lot about engineering.			0.53		
12	I'm excited to come up with my own engineering projects to work on when I see something in VT PEERS that interests me.			0.68		
15	Everyone can learn to do engineering.			0.35		
14	Engineering makes a difference in people's lives.				0.37	
17	Engineers work with many types of people.				0.39	
18	Engineers solve problems.				0.41	
19	Engineers rely on knowledge from multiple subjects.				0.66	
20	Solving engineering design problems requires compromise and trade-offs.				0.52	
28	Engineers build roads, buildings, or bridges.					0.48

(Continued)

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TABLE 3 (Continued)

Item	Wording	F1: common conceptions of engineering	F2: future pursuits of engineering	F3: current engagement with engineering	F4: abstract conceptions of engineering	F5: specific conceptions of engineering
29	Engineers teach others.					0.59
31	Engineers conduct scientific experiments.					0.40
32	Engineers talk to people to understand their problems.					0.48
10	Knowing about engineering is extremely valuable to me.	Removed after first round of analysis with 5 factors, loaded onto factors 2 and 3 (originally from four-phased interest model)				
13	Engineering happens in my community.	Removed after second round of analysis with 5 factors, loaded onto no factors (originally from TTK)				
16	Engineers are creative.	Removed after first round of analysis with 5 factors, loaded onto factors 1 and 5 (originally from TTK)				
26	Engineers fix broken things.	Removed after first round of analysis with 5 factors, loaded onto factors 1 and 5 (originally from years 1 and 2 data)				
27	Engineers use science.	Removed after second round of analysis with 5 factors, loaded onto factors 1 and 5 (originally from years 1 and 2 data)				

between engineering and other areas of STEM described by Silvestri et al. (2021), as well as the "engineer as doer" as described by de Figueiredo (2008). Additionally, we can see that students see engineers as designers and that design is an important part of engineering, related to both the dimensions of engineering and nature of engineering, respectively. These conceptions are relatively common conceptions of what engineering is. While these conceptions are not wrong, they are perhaps demonstrative of an initial type of understanding of engineering, which is important for students exploring engineering for the first time.

The next salient factor is related to more specific conceptions of what engineering is, but things that may still be common or apparent from the intervention. "Specific" is used to describe this factor as the items are aligned with the conceptions that there are certain, more defined activities that engineering is or that engineers do, and the items are more themselves are more descriptive than those in the common conceptions factor. For example, the items in this factor are related to engineers building roads, buildings, and bridges, engineers teaching others, engineers conducting scientific experiments, and engineers talking to people to understand their problems. In the context of this study, these students would have seen engineers doing most of these things– in particular from the engineers who came in to interact with them in the classroom to help support activities and teach students. Additionally, some activities revolved around students fixing mountain roads or students performing experimentation. The fact that these items grouped together may be due to programmatic features of VT PEERS, but they are still salient given their alignment with the dimensions of engineering knowledge (de Figueiredo, 2008).

The final factor dealt with more abstract concepts that could be more related to how engineers work or the impact engineers might have on a larger scale. "Abstract" is used to describe this factor this factor is representative of things engineers do that do not always have a tangible outcome or action. The items in this factor pointed to engineers being able to make a difference in peoples' lives, engineers working with many types of people, engineers solving problems, engineers relying on knowledge from different subjects, and engineering design requiring compromise and tradeoffs. This layer is describing concepts that are less tangible, especially for students who are in the process of developing the cognitive skills to move from concrete to more abstract thought. For example, the items in layer are asking students to consider how engineering might make a difference in peoples' lives and what types of people they may work with– both of which are related to the nature of engineering and the dimension of engineer as a sociologist (de Figueiredo, 2008). Furthermore, students must also consider what problems engineers can solve, what knowledge they must use to solve problems, and what type of compromises they might have to make to solve these problems. All of these aspects are related to the different dimensions of engineering knowledge presented by de Figueiredo (2008) as well as the idea that engineers work in different environments with different types of people (Silvestri et al., 2021).

Understanding differing levels of conceptions of engineering can help educators determine what (mis)conceptions students might have about engineering and can work toward broadening their conceptions as needed. These layers are likely overlapping but development of broader conceptions would likely move students from common understandings to more abstract understandings, as

TABLE 4 Correlation matrix of factors.

Factors	Common conceptions	Future pursuits	Current engagement	Abstract conceptions	Specific conceptions
Common conceptions	1.00				
Future pursuits	0.29	1.00			
Current engagement	0.27	0.50	1.00		
Abstract conceptions	0.58	0.28	0.33	1.00	
Specific conceptions	0.58	0.31	0.24	0.46	1.00

TABLE 5 Internal consistency.

Factor name	Items	Cronbach's α
Common conceptions	21, 22, 23, 24, 25, 30	0.90
Future pursuits	1, 2, 3, 4, 5, 7	0.74
Current engagement	6, 8, 9, 11, 12, 15	0.74
Abstract conceptions	14, 17, 18, 19, 20	0.84
Specific conceptions	28, 29, 31, 32	0.75

TABLE 6 Factor scores from EFA, *N* = 327.

Factor	Mean	Median	SD
Common conceptions	4.239	4.333	0.720
Future pursuits	3.107	3.167	0.773
Current engagement	3.196	3.167	0.726
Abstract conceptions	3.917	4.000	0.712
Specific conceptions	3.840	4.000	0.739

TABLE 7 Comparing pre-tests between groups 1 and 2, significant differences indicated by * and bolded text (N_1 = 134, N_2 = 226), Kruskal-Wallis test.

Factor	Group	Mean	Median	SD
Common conceptions	1	4.150	4.333	0.790
	2	4.249	4.333	0.759
Future pursuits*	**1**	**2.895**	**2.833**	**0.710**
	2	**3.221**	**3.333**	**0.821**
Current engagement	1	3.071	3.167	0.735
	2	3.218	3.333	0.750
Abstract conceptions*	**1**	**3.726**	**3.700**	**0.663**
	2	**4.015**	**4.000**	**0.718**
Specific conceptions*	**1**	**3.622**	**3.500**	**0.685**
	2	**3.926**	**4.000**	**0.760**

TABLE 8 Comparing Group 1 pre- and post-tests, significant differences between pre- and post-test indicated with bold text and * (N_1 = 24), Friedman's ANOVA.

Factor	Test	Mean	Median	SD
Common conceptions*	**Pre**	**4.150**	**4.333**	**0.790**
	Post	**4.617**	**5.000**	**0.847**
Future pursuits*	**Pre**	**2.895**	**2.833**	**0.710**
	Post	**3.352**	**3.333**	**0.731**
Current engagement*	**Pre**	**3.071**	**3.167**	**0.735**
	Post	**3.358**	**3.333**	**0.789**
Abstract conceptions*	**Pre**	**3.726**	**3.700**	**0.663**
	Post	**4.368**	**4.600**	**0.687**
Specific conceptions	Pre	3.622	3.500	0.685
	Post	4.349	4.500	0.755

TABLE 9 Comparing Group 2 pre- and post-tests, significant differences between pre- and post-test indicated with bold text and * (N_2 = 60), Friedman's ANOVA.

Factor	Test	Mean	Median	SD
Common conceptions*	**Pre**	**4.249**	**4.333**	**0.759**
	Post	**4.469**	**4.833**	**0.708**
Future pursuits	Pre	3.221	3.333	0.821
	Post	3.338	3.333	0.891
Current engagement	Pre	3.218	3.333	0.750
	Post	3.324	3.333	0.843
Abstract conceptions*	**Pre**	**4.015**	**4.000**	**0.718**
	Post	**4.272**	**4.400**	**0.725**
Specific conceptions*	**Pre**	**3.926**	**4.000**	**0.760**
	Post	**4.349**	**4.500**	**0.755**

depicted in starting at the bottom of Figure 1 and moving upward. These findings are aligned with other research that suggests that students have varying levels of understanding about scientists and careers in science (Padwick et al., 2022). The activities that educators use to broaden conceptions are particularly important for the messaging that students receive and therefore the conceptions they develop of engineering. Additionally, educators can get some insight into if their intervention was effective at shifting conceptions of engineering. In the case of this study and context, it could be argued that, to some degree, the program was effective at broadening conceptions of engineering for some students, and that students who had more consistent exposure to the engineering activities through multiple years of program participation had more broad conceptions of engineering (as demonstrated by higher averages in Group 2 compared to Group 1).

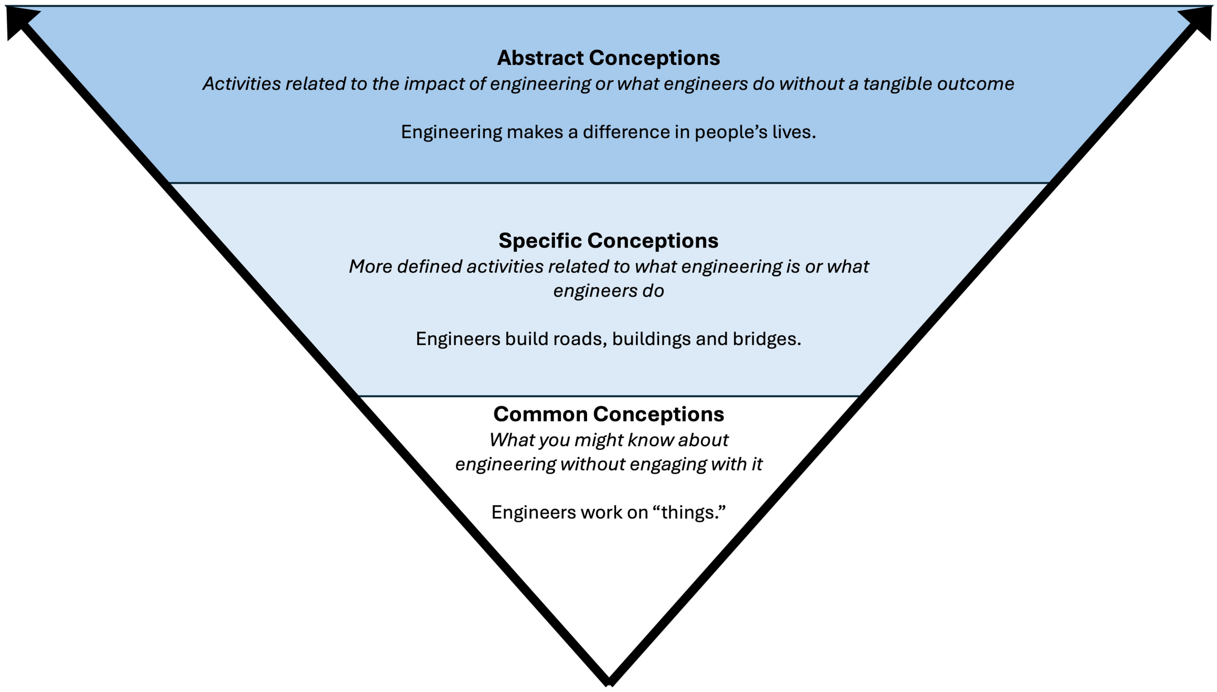

FIGURE 1
Levels of conceptions of engineering.

Measures of conceptions are distinct from but could be related to measures of interest and identity (RQ2)

Next, the results of this study demonstrated that conceptions are not necessarily the same as interest and identity and that they are not necessarily related. The two factors that dealt with this are future pursuits of engineering and current engagement with engineering. Items in these factors included things like working on engineering projects, talking to engineers, learning more about engineering on their own, and using engineering in the future or pursuing engineering as a career. The fact that these items loaded onto factors separate from the conceptions of engineering is important as the average responses for these factors also did not indicate that conceptions and interest and identity are directly related. For example, when it came to looking at the averages for the current engagement and future pursuits, the mean for both groups was often centered around 3, which indicates an overall neutral feeling towards engineering when looking at all the students' responses. This means that while some students may be feeling particularly excited about engineering currently and as a part of their future career path, it is not the case that all students are. However, the averages for the items dealing with conceptions were often higher, closer to the agree to strongly agree end of the Likert scale. This indicates that some students may develop understanding about engineering but not necessarily want to pursue it. On the other hand, students are learning more about engineering and may be excited to pursue it in their present and future.

Ultimately, from this type of intervention, we would expect, and maybe hope, that students learn that engineering is not interesting to them, which can direct them down a different career path. However, it may also point to the fact that, outside of this intervention, these students do not have access to engineering activities that allow them to engage further and develop interest, as is often the case in many rural settings (e.g., Saw and Agger, 2021). Additionally, there may be more work to be done to broaden their conceptions of engineering that may help them realize they are doing engineering in their daily lives– particularly if they work on their family's farm or help repair things at home, as is relatively common with students from rural areas (Avery, 2013; Avery and Kassam, 2011).

The fact that conceptions and interest and identity are distinct factors in this survey also supports research from Pleasants and Olson (2019) that suggests that these things are often conflated on existing surveys. This survey demonstrates a structure in which these things are separate and can be discussed separately, though findings related to factors of conception may point to other issues pertaining to access to engineering and how conceptions may need to be broadened further if students do not realize this is something that is happening in their daily lives. Identifying issues of access alongside these measures is important to understand the full picture of students' interactions with engineering, both as it pertains to developing their conceptions of what engineering is and who can do engineering, but also so that they have the ability to adequately explore the space to maybe spark and foster their interests.

Removed items

The items that were eliminated from the survey were removed because they loaded onto more than one factor or no factors at all. From a methodological standpoint, it is accurate to remove these items and not include them as a part of analysis or in the final version of the survey. However, EFA is a data reduction tool which allows for a better understanding of what is happening within the structure of the survey and how survey respondents are responding to the survey items. Because of the pragmatic nature of this survey in the context of the program, it is important to dig deeper into these items that were removed:

- Item 10—Knowing about engineering is extremely valuable to me.
- Item 13—Engineering happens in my community.
- Item 16—Engineers are creative.
- Item 26—Engineers fix broken things.
- Item 27—Engineers use science.

These items deal with a variety of things, and it is easy to see how some could load onto multiple factors in analysis while others did not at all. Items 13, 16, 26, and 27 dealt with conceptions of engineering and we would have expected them to be grouped as such together in the factor structure. However, items 16, 26, and 27 loaded onto factors dealing with the common conceptions and specific conceptions of engineering. Let us consider item 27 as an example, that engineers use science. The engineering activities in this program took place in the context of the science classroom. Therefore, students may have responded in a way that reflects their association between the engineering activities and being in their science classroom, which means that their varying conceptions of engineering are more associated with science. This conception of engineering, however, is still related to the engineering literacies that seek to emphasize the connections between engineering and other STEM fields (Silvestri et al., 2021). Additionally, there was continuous emphasis throughout the program that engineers are creative, and there were many activities focused on fixing broken things (e.g., mountain roads).

The item we (the project team) were hoping to see in the final structure was item 13, related to engineering happening in the students' communities; however, item 13 did not contribute to the latent structure. Through partnering with local industry in the program activities, we hoped that students would have made the connection that engineering can and does happen locally, and that seeing and knowing these industry professionals would have led to this realization and conception. However, upon reflection and through examining the observation notes, it was apparent that this connection was rarely explicitly stated, leaving students to infer this on their own. For broadening conceptions of engineering, it is important to realize that sometimes purposes need to be directly stated and reiterated to students– we cannot simply assume they will infer conceptions, especially as they are learning to grapple with abstract concepts.

Finally, item 10 deals more with current engagement and future pursuits of engineering and did in fact load onto both of these factors which led to its removal. We would hope that some students learn that engineering is valuable to them while also expecting some students to learn that engineering is not something they are interested in. This would be related to their desire to presently engage with engineering and plans to have engineering be a part of their future pursuits, and therefore, it understandably is related to both factors.

From a practical standpoint, examining the items that were removed more closely helps with understanding what was successful about the intervention, and what may need to be more directly emphasized if we are hoping for students to broaden their conceptions of engineering. However, there are some items that may be removed in the analysis, but that practically make sense to keep on the survey given the context of the intervention and the learning that students may be experiencing about themselves through the intervention.

Conclusions and future work

We conclude that conceptions of engineering can be measured and that there are nuances that can be captured in these conceptions. In this study, common, abstract, and specific conceptions of engineering were able to be parsed from middle school students' responses using preliminary results from an EFA. Notably, these conceptions are separate from what students are currently doing related to engineering and what they might do in the future. Given that our survey demonstrates that interest in and identification with engineering are separate from conceptions of engineering, we recognize that our survey is distinct from surveys that measure engineering identity and therefore offers researchers and practitioners an additional measurement option which selectively compiles some existing instruments but also includes new items entirely. Additionally, the survey was developed through multiple iterations, which was contextualized through observation data and understanding how the results aligned with project goals.

When using survey instruments to measure students' understanding of and beliefs about engineering, our results call for researchers and practitioners to consider what they really want to know and why. As written, the survey can imply that a "5" is a perfect score but in reality we recognize that not every student should want to be an engineer. We might want to see gains in knowledge about what engineering is but that can, and should, lead to disinterest in engineering careers for some students. Therefore, we might want to focus more on understanding distributions of scores and even changes in distributions because there are multiple ways to get to an average score of "3" and those different ways would tell practitioners different things. Essentially the use of this type of survey instrument promotes an opportunity for nuanced conversation about data. While this survey and the data presented is tied to a specific program context, we expect the survey and data can inform research and practice in other contexts. For example, as previously mentioned, this starting point can help educators understand what (mis)conceptions students may have about engineering and how these conceptions may be broadened through educational interventions.

Data availability statement

The datasets presented in this article are not readily available because requests to access raw, de-identified data can be made to the authors, who will work with the university institutional review board to determine if access can be granted. Requests to access the datasets should be directed to Jacob Grohs, jrgrohs@vt.edu.

Ethics statement

The studies involving humans were approved by Virginia Tech Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MS: Writing – original draft, Writing – review & editing. HM: Writing – original draft, Writing – review & editing. JG: Writing – original draft, Writing – review & editing. TP: Writing – original draft, Writing – review & editing. CC: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This material is based upon work supported by the National Science Foundation under grant no. 1657263. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Conflict of interest

CC was employed by E4S, LLC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1538497/full#supplementary-material

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