Enhancing STEM Attitudes of Rural High School Students through Engineering Design-Based Learning

Euisuk Sung, Jung Han, & Todd R. Kelley

Abstract

While STEM education is widely acknowledged for enhancing national competitiveness and fostering creativity and innovation, it's important to note that certain marginalized groups, such as women and rural communities, still need to reap its benefits fully. To address these marginalized groups in the context of STEM education, this study aimed to investigate the impact of rural-focused design-based STEM instruction on high school students' attitudes toward STEM. Additionally, we explored the interplay between gender, school locale, and teachers' perceptions of STEM through multilevel modeling (MLM) analysis.

Our study involved 597 high school students distributed across 35 classes. The results of our MLM analysis revealed a significant difference in STEM attitudes between genders following participation in the design-based STEM instruction, while no regional disparities were identified. Furthermore, our comprehensive MLM model analysis indicated a positive relationship between teachers' perceptions of the importance of STEM and students' attitudes toward STEM. This study implies that incorporating culturally familiar topics into design-based STEM instruction can enhance the STEM attitudes of rural high school students.

Introduction

Enhancing students' competencies in science, technology, engineering, and mathematics (STEM) has held a prominent educational position for over two decades (National Research Council, 2011; Xie et al., 2015; Kelley & Knowles, 2016). This emphasis has grown substantially as 21st-century skills, including creativity, communication, collaboration, and critical thinking, have become increasingly vital in modern society (Jang, 2016; National Research Council, 2010). Nevertheless, certain segments of the postsecondary student population, particularly women and individuals in rural areas, find themselves on the margins of STEM disciplines (Fraser et al., 2019; Mutambara & Bayaga, 2021).

Keywords: STEM Attitudes, Engineering Design-Based Learning, Locational Disparities

Sung, E., Han, J., & Kelley, T., (2025). Enhancing STEM Attitudes of Rural High School Students through Engineering Design-Based Learning, *36*(2), 113-137. https://doi.org/10.21061/jte.v36i2.a.6

Moreover, despite comprising more than two-thirds of college students, women and minorities remain significantly underrepresented in STEM disciplines (Taylor et al., 2020). Goodpaster et al. (2012) highlight that at the secondary level the low performance in STEM subjects by students in rural schools is reflective of the current international trend, with the gap widening due to factors such as teacher quality, insufficient resources, financial support, and economic inequality. However, regardless of educational level, failing to actively involve these underrepresented groups in STEM disciplines not only hampers their ability to meet the demands of the STEM workforce but also hinders the realization of an educational vision centered on equity and the cultivation of informed democratic citizens.

Locational Disparities

Rural areas in particular face significant marginalization in the realm of STEM education. This issue is not unique to the United States but is a global concern, with the gap between urban and rural areas widening (Harris & Hodges, 2018; Zarifa et al, 2019). Gonzalez and Kuenzi (2012) reported that student achievement in STEM fields in rural and urban areas consistently lags behind that of suburban areas. In rural areas, students encounter limited opportunities for STEM education, which subsequently reduces their prospects of securing STEM-related employment (Lavalley, 2018). The rural-urban disparity in STEM education is not solely a matter of differences in socioeconomic status; it is also influenced by broader factors encompassing culture, student identity, motivation, teacher recruitment and training, and the overall context of STEM education (Biddle & Azano, 2016). Haron et al. (2019) revealed that a significant number of rural students perceived a disconnection between the STEM education they receive and its relevance to their daily lives. Woolfolk (2019) noted that educational psychology indicates that context is a crucial developmental element that envelops and interacts with an individual's thoughts, feelings, and actions, influencing their learning experiences.

Further exacerbating locational disparities, the issues related to gender and location are intertwined with regions, academic disciplines, prevalent stereotypes, and broader sociocultural factors. Makarova et al. (2019) discovered that secondary male and female students tended to perceive school STEM subjects as having dominantly masculine attributes. Importantly, their study underscored that these gender stereotypes play a significant role in dissuading female students from pursuing STEM majors at the university level. In a separate study conducted by Cardador et al. (2021), it was observed that even when female students harbor an interest in STEM fields, they are more inclined to opt for non-STEM disciplines when presented with alternative choices. Furthermore, it's essential to recognize that students' interest in STEM is closely linked to their subsequent career choices and academic achievement (Maltese & Tai, 2011; Simpson et al., 2021; van Tuijl & van der Molen, 2016; Wang, et al., 2017). Previous studies indicated that interest is not solely a matter of vocabulary or definition; it is intricately tied to when and how interest develops. For example, Simpson et al. (2021) determined that the development of an individual's identity plays a pivotal role in shaping their path toward a STEM career, and this identity formation is significantly influenced by the context in which the student resides.

Potential of Engineering Design-Based Learning

Engineering design-based learning has been recognized as an effective strategy for STEM education (Shanta & Wells, 2020). This pedagogical approach employs engineering design to tackle engineering-related challenges while fostering systematic methods, systemic thinking, critical analysis, and collaborative skills (Gómez Puente, Van Eijck, & Jochems, 2014; Lin, et al., 2021). Although it is akin to project-based learning, design-based learning distinctly prioritizes the design process and its resulting artifacts. This pedagogical approach exemplifies integrative STEM education (Wells, 2013, 2016a), as it promotes transdisciplinary learning by addressing real-world challenges and devising solutions through design, thus leveraging integrative STEM education. The pedagogy of engineering design-based learning is rooted in constructivist theory, which highlights the active role of learners in constructing their knowledge through learning experiences and social interactions. Teaching STEM through engineering design-based instruction utilizes scientific inquiry, engineering design, problem-solving, collaboration, and cooperative learning to encourage self-directed learning of students (Kelley & Knowles, 2016). Furthermore, engineering design-based instruction intentionally combines technological design with scientific inquiry to tackle issues pertinent to students' context. This approach underscores the significance of the social interaction and cultural context within which learning occurs (Dym et al., 2005). Previous studies indicated that design-based learning narrows the gender gaps and perceptions surrounding STEM by incorporating real-world challenges into the classroom (Phothong et al., 2023). When implementing engineering design-based instruction, the learning process unfolds within a real-world context or a similar setting, facilitated by collaboration within a community of practice, transcending the traditional boundaries of school subjects (Breiner et al., 2012).

The engineering design-based learning approach, which employs culturally relevant contexts, provides the opportunity for students to engage with real-world problems they encounter in their own lives and presents a viable pedagogical approach for positively influencing student attitudes toward STEM education. As a measure of this viability, this study employed engineering design-based instruction as an intervention to examine its impact on student attitudes toward STEM.

Research Questions

The goal of this study was to characterize the impact of engineering design-based learning featuring a rural context on high school students' attitudes toward STEM. The study sought to achieve this goal through analysis of the relationships between gender and school location of students together with teacher perceptions of STEM education in the context of engineering design-based learning through multilevel modeling analysis (MLM). Guiding this investigation were the following three research questions:

1. Do rural students exhibit distinct STEM attitudes compared to students from other locales after engineering design-based learning within a rural context?
2. Do female students exhibit district STEM attitudes compared to their male counterparts after engineering design-based learning within a rural context?
3. What relationships exist between teacher's perceptions of the importance of STEM and students' attitudes toward STEM following engagement in an engineering design-based learning within a rural context?

Literature Review

STEM Attitudes

Recent studies indicate that integrative STEM education plays a significant role in shaping students' inclinations toward STEM, enhancing their academic performance in STEM subjects, and positively influencing their career decisions (Wells, 2016b; Haron et al., 2019; Maltese & Tai, 2011). Hall et al. (2011) revealed that students' interest and persistence in STEM have significant relationships with their choices of STEM careers. Dou et al. (2019) identified that STEM identity in the early stage is a pivotal factor in their career choices. Their study found that the STEM identity of young students plays a significant element while controlling other factors in choosing a STEM career in college. Tseng et al. (2013) confirmed that students' attitude toward STEM influences their career development and acquisition of knowledge and skills in STEM fields. Furthermore, Popa and Ciascai (2017) conducted interviews with 110 college students. They discovered that the positive experiences in secondary STEM classes and with teachers were the key influences on their career choices in STEM. Sirakaya et al. (2020) also investigated the dynamic relationship between STEM attitudes and students' thinking skills. They found that secondary students with positive STEM attitudes tended to demonstrate advanced 21st-century skills, including creativity, critical thinking, and problem-solving when compared to their peers in the comparison group.

When assessing STEM attitudes, the underlying subcomponents are typically rooted in two pivotal psychological concepts: self-efficacy and expectancy-value beliefs (Eccles & Wigfield, 2002; Unfried et al., 2015; Han et al., 2021). Self-efficacy, as defined by Bandura (1993), refers to an individual's confidence in their ability to organize and execute a particular course of action to solve a problem or achieve a task. Expectancies pertain to individuals' expectations regarding their performance on various tasks or activities, while value relates to the motives or goals driving their actions. Unfried et al. (2015) developed the Student Attitudes Toward STEM (S-STEM) instruments, which encompass four key factors: attitudes toward mathematics, science, engineering/technology, and attitudes toward 21st-century skills. These instruments propose that STEM attitudes are composed of two psychometric elements: self-efficacy and expectancy-value beliefs.

STEM attitude has been investigated from the integrated perspective as well as through the single-subject approach. In technology and design education, Pupils' Attitudes Toward Technology (PATT) has been used to measure students' interest and attitude towards technology. Raat and DeVries (1985) developed the PATT instrument to evaluate students' perceived concepts related to technology, thereby measuring their attitudes toward STEM fields. The PATT instrument encompasses three key components: conception, career aspirations, and interest in technology (Bame et al., 1993). Over the course of more than three decades, the PATT instrument has been widely utilized in numerous international studies and has significantly contributed to identifying trends and patterns in students' attitudes toward technology (Svenningsson et al., 2018).

In science education, various measurements and assessing approaches were introduced (Osborne et al., 2003). Wang and Berlin (2010) introduced a tool to assess scientific attitudes to determine an opinion or position on a psychological object in the field of science. Benek and Akcay (2018) presented an attitude scale for secondary school students toward STEM. They confirmed that the psychometrics of students' STEM attitudes have six factors: science, mathematics, engineering, technology, STEM, and career. Furthermore, Kind et al. (2007) developed a survey tool to gauge pupils' attitudes toward science. This tool delves into various dimensions, including students' feelings, opinions, beliefs, and preferences concerning science. It covers a range of aspects, such as learning science in school, engaging in practical work in science, interactions with science beyond the classroom, the perceived importance of science, self-concept in the field of science, and future intentions for involvement in scientific pursuits.

Regional and Gender Gaps in STEM Education

Showalter et al. (2017) reported that students residing in rural areas exhibited lower performance on national-level reading and mathematics tests in grades 4 to 8, which are the critical period of career choices in relation to STEM (Maltese & Tai, 2011). Additionally, the report noted that lower academic achievements had significantly lower high school graduation rates, exemplified by Alaska's rate of 60.9 % compared to Connecticut's 94.3 %. Mau and Li

(2018) conducted similar research in which they investigated factors influencing high school students' career choices. Their study discovered that race, gender, and socioeconomic status wielded significant influence on STEM career aspirations, alongside factors such as interest in science and mathematics. These results indicate that students from underrepresented groups tend to opt for non-STEM majors compared to the other groups.

Previous research has unearthed several significant factors that contribute to the gender gap in STEM (Ciftci et al., 2020). Tyler-Wood et al. (2012) contended that the disparity in STEM academic achievements between genders is more closely associated with students' perceptions of STEM than their inherent abilities. Their study demonstrated that positive learning experiences in STEM had a notable impact on increasing STEM interest, altering perceptions, and enhancing career intentions among female students. Shin et al. (2015) investigated the factors that influence gender differences, examining both factors within the home and motivational factors. Their findings emphasized the significance of gender similarities, rather than differences, in shaping career awareness in science. For instance, when parents hold positive perceptions of STEM, their female children are more likely to place higher value on and exhibit greater motivation in STEM.

As women are underrepresented in STEM fields, it is common for female students to possess a lower perception of STEM careers and identities (Cowgill et al., 2021; Swafford & Anderson, 2020). This can subsequently lead to decreased motivation and interest in STEM (van den Hurk et al., 2018; Talafian et al., 2019). Wegemer and Eccles (2019) proposed a model based on the Expectancy-Value Theory to elucidate the gender gap in STEM. Their model revealed that values, gender-related beliefs, and one's sense of identity in relation to STEM are intertwined with behaviors related to achievement. These behaviors, in turn, contribute to the gender disparities observed in STEM. Their study provided that STEM career paths may be influenced by the alignment of values, identity, and gender-related beliefs regarding STEM fields. Additionally, O'Dea et al. (2018) investigated gender differences in school performance to pinpoint the origins of gender disparities in STEM careers. Interestingly, for the top 10% of students, their study found that an almost equal number of male and female students were enrolled in STEM subjects. Conversely, non-STEM subjects saw a higher proportion of female students. Specifically, they found that fewer female students with strong academic achievement tended to choose STEM careers, while middle to low-performing male students are inclined to pursue STEM fields.

In addition to students' perceptions and career choices, researchers have uncovered the significant influence of teachers' perceptions and school culture on students' STEM career decisions. Hand et al. (2017) reported that high school teachers often hold gender stereotypes in STEM, associating masculine traits with the typical scientist and mathematician. Furthermore, Wahono and Chang

(2019) found that male teachers tend to exhibit more positive attitudes toward STEM compared to their female counterparts, even though their STEM knowledge levels did not show significant differences.

Engineering Design-based Learning

Design-based learning is an instructional approach featuring design as a primary tool in project-based settings (Gómez Puente et al., 2014). Engineering design specifically, is a systematic, intelligence process for solving problems through generating, evaluating, and specifying concepts while satisfying a set of constraints (Dym et al., 2005). Engineering design-based learning includes characteristics of project-based learning, such as being student-centered, hands-on, collaborative, critical thinking, and creative, but additionally emphasizes an open-ended design process. In contrast, Fortus et al. (2004) proposed design-based science as an approach to teaching science using design activities for real-world problem-solving. They suggested that design-based science restructures school science curricula by featuring scientific inquiry as an integral component of design to address real-world challenges. While engineering design-based instruction shares similarities with other student-centered approaches like inquiry-based, problem-based, and project-based learning, it possesses unique characteristics (ITEEA, 2020). Specifically, engineering design-based activities addressing real-world problems result in the creation of artifacts that represents the mental concept, often mirroring the original idea or actual objects (Goldschmidt, 1991). Katehi et al. (2009) defined the nature of engineering design as highly iterative, open to the idea that a problem may have multiple possible solutions, serving as a meaningful context for comprehending scientific, mathematical, and technological concepts and stimulating systems thinking, modeling, and analysis.

Numerous research studies have reported that engineering design-based learning has yielded positive outcomes, including enhanced knowledge acquisition (Wells, 2021; English & King, 2015), increased creativity (Altan & Tan, 2021), improved problem-solving skills (Lin et al., 2015), heightened interest in STEM (Hall et al., 2011), greater motivation (Haron et al., 2019), and heightened career awareness (Maltese & Tai, 2011; Sadler et al., 2012). Similarly, Thibaut et al. (2018) claimed engaging in design activities within STEM education empowers students to apply scientific knowledge, aesthetic design principles, and mathematical skills collaboratively to arrive at solutions (Riskowski et al., 2009). Shanta and Wells (2020) also identified that students who participate in engineering design-based learning significantly improve their problem-solving and computational thinking skills. Additionally, the National Research Council (2009) reported that engineering design-based learning fosters engineering habits of mind among students, including systems thinking, creativity, optimism, collaboration, communication, and ethical considerations.

Research Method

Context of Study

The Teachers and Researchers Advancing Integrated Lessons in STEM (TRAILS) project (NSF AWARD #1513248) was initiated to better understand and promote pedagogical practices that increase students' motivations and capacities to pursue careers in STEM through innovative technology experiences for students residing in rural areas in the U.S. The project was conducted during the academic years 2016-2019. This initiative involved the active participation of high school biology and engineering and technology education (ETE) teachers. As part of the TRAILS project, the team developed an exemplary lesson known as Designing Bugs and Innovative Technology (DBAIT), which seamlessly integrated concepts from the fields of entomology and biomimicry into engineering design-based instruction. To prepare the STEM teachers for the implementation of these lessons, an extensive two-week summer professional development (PD) program was conducted, encompassing over 70 hours of training. During this PD, educators were not only introduced to the DBAIT lesson but were also provided with the opportunity to experience it from a student's perspective. This pedagogical approach aimed to equip teachers with the skills and knowledge required to effectively deliver these lessons in their own classrooms.

During the summer PD, biology and ETE teachers worked together in pairs collaborating on crafting custom lessons that seamlessly integrated scientific principles and engineering practices. In the subsequent school year, these educators implemented two integrated STEM lessons – DBAIT and their custom-designed lesson – into their respective classrooms. Throughout this process, the TRAILS researchers and graduate students supported the teachers to develop a community of practice within the classrooms. This community of practice extended beyond the classroom, as teachers reached out to local experts to enhance their understanding of the engineering design activities, which, in this case, involved delving into topics such as aquatic entomology, fish food chains, and general ecology.

Participants

The total number of participants included in this study was 597 high school students taking biology or engineering and technology education (ETE) classes in the Midwest. The demographics displayed in Table 1 show that the proportions of males and females were 62.8% and 37.2%, respectively.

Table 1

Demographics of the Participant Students (2016-2019)

Class Subjects		Participant Demographics (n = 597)							
		Gender		Ethnicity					
ETE	Biology	Male	Female	White	Black	Hispanic	Asian	Multi	Other
218 (36.5%)	379 (63.5%)	375 (62.8%)	222 (37.2%)	504 (84.4%)	19 (3.2%)	52 (8.7%)	15 (2.5%)	1 (0.2%)	6 (1%)

Data Collection

To measure students' attitudes toward STEM, we used the science, mathematics, and engineering attitudes from the S-STEM Survey (Unfried et al., 2015). Additionally, we used the Importance Subscale from the DET section of the Teacher’s Perceptions of Engineering and their Familiarity with Teaching Design, Engineering, and Technology (DET) survey developed by Yaşar et al. (2006). These survey data were collected after the participating teachers implemented an engineering design-based STEM unit set in a rural context. The researchers obtained approval from the Institutional Review Board (IRB) before collecting the data.

S-STEM Survey

The S-STEM survey was used to measure secondary students’ STEM attitudes and career interests (Unfried et al., 2015). The survey consists of six subscales. The present study used the first three subscales, Math Attitudes, Science Attitudes, and Engineering and Technology Attitudes, to measure student STEM attitudes (Table 2). The instrument developers confirmed the reliability and validity of the survey instrument. For the middle and high school S-STEM survey, the Cronbach’s Alpha reliability level of each Math Attitudes, Science Attitudes, and Engineering Technology Attitudes, was 0.90, 0.89, and 0.89, respectively (Unfried et al., 2015). Construct validity was confirmed through exploratory factor analysis (EFA) that the four factors of mathematics, science, engineering, and 21st-century skills explained approximately 70% of students’ STEM attitudes. Content validity was also confirmed by subject matter experts (SMEs): “three SMEs rated each item as essential, useful but not essential, or not necessary for measuring the given construct,” and item-level content validity ratios were calculated from the responses (Unfried et al., 2015, p. 625). Table 2 displays the survey items for STEM attitudes. A 5-point Likert scale (strongly disagree (1) to strongly agree (5)) was used for the STEM attitudes subscales. The items denoted (-) in Table 2 represent negatively worded item.

Table 2

S-STEM Survey STEM Attitudes Items (Friday Institute for Educational Innovation, 2012e, p.1)

S-STEM Attitudinal Items	
Discipline	**Item**
Math	
	Math has been my worst subject. (-)
	I would consider choosing a career that uses math.
	Math is hard for me. (-)
	I am the type of student to do well in math.
	I can handle most subjects well, but I cannot do a good job with math. (-)
	I am sure I could do advanced work in math.
	I can get good grades in math.
	I am good at math.
Science	
	I am sure of myself when I do science.
	I would consider a career in science.
	I expect to use science when I get out of school.
	Knowing science will help me earn a living.
	I will need science for my future work.
	I know I can do well in science.
	Science will be important to me in my life's work.
	I can handle most subjects well, but I cannot do a good job with science. (-)
	I am sure I could do advanced work in science.
Engineering and Technology	
	I like to imagine creating new products.
	If I learn engineering, then I can improve things that people use every day.
	I am good at building and fixing things.
	I am interested in what makes machines work.
	Designing products or structures will be important for my future work.
	I am curious about how electronics work.
	I would like to use creativity and innovation in my future work.
	Knowing how to use math and science together will allow me to invent useful things.
	I believe I can be successful in a career in engineering.

Note: (-) = items negatively worded

Design, Engineering, and Technology (DET) Survey

To investigate the relationships between teacher's perceptions of STEM and students' attitudes toward STEM, we used the Teachers' Perceptions of

Engineers and Familiarity with Teaching Design, Engineering, and Technology (DET) survey (Yaşar et al., 2006). The original survey consists of 41 items, but our study used the first subscale Importance of DET (Table 3), to measure teachers' perception of the importance of STEM. The alpha coefficient for this subscale, Importance of DET, was 0.91.

Table 3

*Teacher Survey Subscale: Importance of DET (*Yaşar et al., 2006*)*

Importance Subscale Items
I would like to be able to teach my students to understand the use and impact of DET.
I would like to be able to teach my students to understand the science underlying DET.
I would like to be able to teach my student to understand the design process.
I would like to be able to teach students to understand the types of problems to which DET can be applied
My motivation for teaching science is to promote an understanding of how DET affects society
I am interested in learning more about DET though in-service
I would like to be able to teach students to understand the process of communicating technical information
My motivation for teaching science is to prepare young people for the world of work.
My motivation for teaching science is to promote an enjoyment of learning.
I believe DET should be integrated into the K-12 curriculum.
I am interested in learning more about DET through workshops.
I am interested in learning more about DET through college courses.
In a science curriculum, it is important to include the use of engineering in developing new technologies.
I am interested to learning more about DET through peer training.
My motivation for teaching science is to help students develop an understanding of the technical world.
My motivation for teaching science is to educate scientists, engineers, and technologists for industry.
In a science curriculum, it is important to include planning of a project.
How important should pre-service education be for teaching DET?

Data Analysis

Given students were nested within each class, multilevel modeling (MLM) analysis was conducted using the HLM 8 software. For the descriptive statistics, the SPSS 26 software was used. Student STEM attitude was set as a dependent variable. Student gender (Female = 1, Male = 0) was a level 1 (student level) predictor variable. The level 2 (classroom level) predictors included teachers' perception of the importance of design, engineering, and technology (DET) as measured by the DET survey (Yaşar et al., 2006), and class locale. The class locale type (Rural, Town, Suburb, and City) was dummy-coded, and *Rural* was set as the reference group.

The unconditional model (null model) did not include any predictors. The random coefficient model included student gender as a level 1 predictor (student level) to examine if the students' STEM attitude following engineering design-based integrated STEM instruction, differs by gender (RQ 1). The final wholly conditional model (intercept-and slope-as-outcomes model) contained three independent variables including gender, DET, and class locale, to examine if the average scores of STEM attitude of the classes in a rural area differed from those of other classes (RQ 2) and if teachers' perception of the importance of design, engineering, and technology (DET) relates to the class average scores of STEM attitude (RQ 3). The Level 1 predictor, gender, was uncentered, and the Level 2 predictors were group-centered. The Level 1 and Level 2 final, fully conditional models (intercept- and slopes-as-outcomes model), are as follows:

Level 1 Model:

$$STEM\_attitude_{ij} = \beta_{0j} + \beta_{1j}*(Female_{ij}) + r_{ij}$$

Level 2 Model:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}*(DET_j) + \gamma_{02}*(Town_j) + \gamma_{03}*(Suburb_j) + \gamma_{04}*(City_j) + u_{0j}$$
$$\beta_{1j} = \gamma_{10} + \gamma_{11}*(DET_j) + \gamma_{12}*(Town_j) + \gamma_{13}*(Suburb_j) + \gamma_{14}*(City_j) + u_{1j}$$

Mixed Model:

$$\text{STEM\_attitude}_{ij} = \gamma_{00} + \gamma_{01}*\text{DET}_j + \gamma_{02}*\text{Town}_j + \gamma_{03}*\text{Suburb}_j + \gamma_{04}*\text{City}_j + \gamma_{10}*\text{Female}_{ij} + \gamma_{11}*\text{DET}_j*\text{Female}_{ij} + \gamma_{12}*\text{Town}_j*\text{Female}_{ij} + \gamma_{13}*\text{Suburb}_j*\text{Female}_{ij} + \gamma_{14}*\text{City}_j*\text{Female}_{ij} + u_{0j} + u_{1j}*\text{Female}_{ij} + r_{ij}$$

In the Mixed Model formula, STEM attitude_{ij} represents STEM attitude score for student i in class j, β_{0j} and β_{1j} represent the random coefficients of each group, $\gamma_{00} – \gamma_{14}$ represents the fixed effects coefficients, u_{0j} represents the variation across classes, and r_{ij} represents the variation within class j (Suárez, & Wright, 2019).

Findings

Descriptive statistics

The analysis of Multilevel Modeling included 597 students nested within 35 classes. Tables 4 and 5 display descriptive statistics by gender and locale type where classes were taught. In the Level 1 Model, the average score of the dependent variable, STEM attitude, was 88.88 (SD = 16.33, skewness = 0.03, kurtosis = 0.293), and the averages of female and male were 83.12 and 92.30, respectively (see Table 4). For the Level 2 Model, we calculated the students' STEM attitudes and DET at class level to identify the effect of locale that the class belongs to instead of individual student scores. The averages of STEM attitudes by locale had a moderate variation range from 86.90 in town to 89.90 in suburban. We collected the DET scores from the classroom teachers and the average of four locales was 75.57 (SD = 9.998, skewness = 0.041, kurtosis = 0.528)

Table 4

Students' STEM Attitude by Gender and Locale Type

Variables (N)	STEM Attitude	
	M	*SD*
Gender (597)		
Female (222)	83.12	15.79
Male (375)	92.30	15.69
Locale (35)		
Rural (26)	88.75	16.17
Town (2)	86.90	12.01
Suburb (2)	89.90	16.35
City (5)	89.09	17.30

Table 5

Teacher Perception Locale

Variables (N)	DET	
	M	*SD*
Locale (35)		
Rural (26)	76.71	11.43
Town (2)	78.20	9.30
Suburb (2)	69.48	3.39
City (5)	73.94	3.09

Gender Differences in STEM Attitudes

To answer Research Question 1 (Do rural students exhibit distinct STEM attitudes compared to students from other locales after engineering design-based learning within a rural context?) we conducted an MLM analysis using the Level 1 model. Table 6 shows the results of the MLM analysis. The intraclass correlation coefficient for the unconditional is 0.221, which indicates that about 22.1% of the total variation in the student STEM attitude scores is associated with the classroom difference. The analysis of the random coefficient model revealed that gender (Female) is a significant predictor of student STEM attitude (γ_{10} = -5.037, t (34) = -3.141, p = 0.003), which indicated that a female student's STEM attitude score was 5.037 points lower than that of a male student. The gender differences were consistent across classrooms (τ_1^2 = 15.857, χ^2 (28) = 36.975, p = 0.119), which means that the size of the gender difference is consistent as 5.037 points across classes. This result found that female students' STEM attitudes are lower than male students across the locales.

Table 6

The results of MLM analyses for gender and locations

	Unconditional Model		Random Coefficient Model		Intercept-and Slope-as-Outcomes Model	
Fixed Effect	Estimate	SE	Estimate	SE	Estimate	SE
Gender (β1j)						
Intercept (γ10)			-5.04**	1.53	-5.30**	1.85
DET (γ11)					-0.11	0.19
Town (γ12)					-1.51	10.89
Suburb (γ13)					-6.87	7.56
City (γ14)					3.02	4.39
Intercept (β_{0j})						
Intercept (γ_{00})	90.46***	1.50	92.50 ***	1.26	92.54***	1.25
DET (γ_{01})					0.33*	0.13
Town (γ_{02})					-0.12	9.21
Suburb (γ_{03})					0.67	4.64
City (γ_{04})					3.18	3.29

Variance Estimates	Variance	Variance	Variance
Between-Classroom			
Intercept (τ_0^2)	61.37***	34.78***	26.00***
Gender Slope (τ_1^2)		15.86	29.22*
Within-classroom (σ^2)	216.09	207.99	208.22

Note. * p < 0.05; ** p < 0.0; *** p < 0.001.

Locational Difference in STEM Attitudes

We conducted a mixed model analysis to test Research Question 2 (Do female students exhibit district STEM attitudes compared to their male counterparts after engineering design-based learning within a rural context?), examining the locale effect on students' STEM attitudes. The results shown in Table 6 indicate that there were no significant regional differences in the students' STEM attitudes. Reviewing mean STEM attitude scores of students shows slight differences in Town (γ_{02}) (*B* = -0.117, *t* (30) = -0.013, *p* = 0.990), Suburb (γ_{03}) (*B* = 0.671, *t* (30) = 0.145, *p* = 0.886), and City areas (γ_{04}) (*B* = 3.183, *t* (30) = 0.968, *p* = 0.341), but our model did not find statistical evidence that the difference in STEM attitudes is related to the locale of students. This result shows no difference in the effect by region when the same engineering design-based learning is provided.

Gender (γ_{10}) was found to be a significant predictor of student STEM attitude (*B* = -5.299, *t* (30) = -2.861, *p* = 0.008), which indicates that the average STEM attitude score of female students in rural classrooms was 5.299 points lower than that of male students in Rural classrooms. However, when gender was assigned as a fixed effect, the intercept-and slope-as outcome model showed no significant interaction effects between gender and other predictors.

Relationship between Teachers' Perceptions of STEM and STEM Attitudes

To examine Research Question 3 (What relationships exist between teacher's perceptions of the importance of STEM and students' attitudes toward STEM following engagement in an engineering design-based learning within a rural context?), we conducted a Mixed Model analysis. Table 6 indicates that the variations of DET and Locale did not statistically contribute to the variation of gender effect. The random effect in this model suggests that the conditional mean of student STEM attitude varies across schools ($\tau_0^2 = 26.003$, χ^2 (24) = 60.660, $p < 0.001$). Additionally, the association between STEM attitude and gender varies across schools ($\tau_1^2 = 29.217$, χ^2 (24) = 36.505, $p < 0.049$). Compared to the unconditional model, 57.6% of the variance is reduced by adding level 2 predictors, DET and Locale, to the fully conditional model (τ_0^2 = 26.003) (Raudenbush & Bryk, 2002). Therefore, the final fully conditional model, intercept-and slope-as-outcomes model, revealed that teacher perception of the importance of DET (γ_{01}) was positively associated with student STEM attitude (B = 0.329, t (30) = 2.514, p < 0.018).

Discussion

Over the past two decades, the significance of STEM education has been discussed with the context of a *STEM for All* educational movement. This educational movement has been pivotal in addressing the historical exclusion of certain groups, including females and those in rural areas, from STEM education (Committee on STEM Education of the National Science and Technology Council, 2018). Previous research and educational practices have consistently emphasized the importance of providing all students, regardless of their backgrounds, with equitable opportunities to engage in STEM learning (Lavalley, 2018; Zarifa et al., 2019). Furthermore, research has identified that one of the most effective approaches to ensure STEM education is accessible to all groups is by bringing real-world problems into the classroom and engaging students in problem/project-based, student-centered, and engineering design-based learning (Han et al., 2021; Sanders, 2009). Implementing culturally relevant and equitable engineering design-based learning is essential to promote student engagement in STEM learning for underrepresented groups. However, it remains a challenge to engage female students in STEM education. Recognizing this issue, our research team developed and implemented a STEM education program for high school students set in a rural context.

Engineering design-based learning as presented in this study was designed to foster active engagement in the learning process for all students. Our approach to engineering design-based learning promoted student engagement by incorporating their local surroundings together with elements of entomology, biology, and engineering design into the educational process. The findings of this study indicate that males exhibited a greater interest in STEM, aligning with previous research (Ciftci et al., 2020). However, while prior studies have suggested that students in rural areas generally exhibit lower interest in STEM compared to their urban counterparts, this study did not find a statistically significant difference by locale (Unfried et al., 2014). This suggests that engineering design-based learning contextualized in a rural setting may have mitigated the previously observed gap in STEM attitudes between rural and urban students.

Implication and Limitation

There still exist significant disparities by gender and location in access to and engagement in STEM education. The proportion of female students pursuing STEM education and the workforce is considerably lower than that of males (Bird & Rhoton, 2021). Research suggests that female students' lower interest and attitudes toward STEM contribute to this gender imbalance in the STEM workforce (Makarova et al., 2019). The issue of gender disparity in

STEM careers remains a critical challenge that hinders increasing diversity, equity, and inclusive STEM education (Merayo & Ayuso, 2023). The issue of gender disparity in the STEM fields continues to be a critical problem that weakens the STEM pipeline (van der Vleuten et al., 2018). Likewise, the present study found that these gender differences were prevalent across different locales. Previous studies have discussed a number of social and psychological factors considered to be barriers to women entering STEM fields, including learning style (Kulturel-Konak et al., 2011), identity (Simpson & Bouhafa, 2020), gender stereotype (Ertl et al., 2017). Our study suggests that future research is needed on identifying best practices to increase women's participation.

Our study did not find significant disparities in STEM attitudes by class locales. Although this study conducted MLM analysis by gender and region, the authors acknowledge that many school and student factors interact in complex ways. In light of this, future research is needed to investigate what methods might prove to be effective in providing rural and female students with authentic, engineering design-based learning specifically tailored to the unique characteristics of these groups, beyond just gender and region. It has been reported that students in rural areas are more marginalized from STEM education than those in urban or suburban areas (Harris & Hodges, 2018). Regarding the marginalization of rural districts from STEM education, our research provides evidence that implementing engineering design-based learning contextualized in the local context, has the potential for contributing to closing regional disparities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The first author primarily contributes to this article by conducting a literature review, organizing data, and reporting the results and discussions. The second author collected data and conducted MLM analyses. The third author was the research project's principal investigator who contributed to developing the research framework, questions, and methodologies. All authors collectively contributed to collecting and analyzing the data and writing the manuscript.

Funding

This work is based upon work supported by the National Science Foundation under Grant No (#1513248). Any opinions, findings, 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.

Ethical Approval

Research on human subjects has been approved by the Institutional Review Board (IRB) at Purdue University. All participants provided informed consent for participation in this study. No sufficiently identifiable information about participants was included in this manuscript. Informed consent was received from all participants for participation in the project. The research was performed per the ethical standards outlined in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

References

Altan, E. B., and Tan, S. (2021). Concepts of creativity in design based learning in STEM education. *International Journal of Technology and Design Education, 31*, 503-529. doi:10.1007/s10798-020-09569-y

Bame, E. A., Dugger, W. E., de Vries, M., and McBee, J. (1993). Pupils' attitudes toward technology—PATT-USA. *The Journal of Technology Studies, 19*, 40-48.

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist, 28*, 117–148. doi:10.1207/s15326985ep2802_3.

Benek, İ., and Akçay, B. (2018). STEM in The My Imaginary World! Investigation of Student's Drawings in STEM Field. *Journal of STEAM Education, 1*, 79-107.

Biddle, C., and Azano, A. P. (2016). Constructing and reconstructing the "rural school problem" a century of rural education research. *Review of Research in Education, 40*, 298-325. doi:10.3102/0091732X16667700

Bird, S. R., & Rhoton, L. A. (2021). Seeing isn't always believing: Gender, academic STEM, and women scientists' perceptions of career opportunities. *Gender & Society, 35*(3), 422-448. doi:10.1177/0891243221100881

Breiner, J. M., Harkness, S. S., Johnson, C. C., and Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11. doi:10.1111/j.1949-8594.2011.00109.x

Cardador, M. T., Damian, R. I., and Wiegand, J. P. (2021). Does More Mean Less?: Interest Surplus and the Gender Gap in STEM Careers. *Journal of Career Assessment, 29*, 76-97. doi:10.1177/1069072720930658

Ciftci, A., Topcu, M. S., and Erdogan, I. (2020). Gender Gap and Career Choices in STEM Education: Turkey Sample. *International Journal of Progressive Education, 16*, 53-66. doi:10.29329/ijpe.2020.248.4

Cowgill, C., Halper, L., Rios, K., & Crane, P. (2021). "Why so few?": Differential effects of framing the gender gap in STEM recruitment interventions. *Psychology of Women Quarterly, 45*(1), doi:61-78. 10.1177/03616843209651

Committee on STEM Education of the National Science and Technology Council. (2018). *Charting a course for success: America's strategy for STEM education*. Washington, DC. Available at https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf Accessed on February 18, 2020.

de Vries, M. J. (2021). Design-based learning in science and technology as integrated STEM, Chapter 2, pp. 14-24 in Ineke Henze and Marc J. de Vries (Eds.) In *Design-Based Concept Learning in Science and Technology Education*. doi:10.1163/9789004450004_002

Dou, R., Hazari, Z., Dabney, K., Sonnert, G., and Sadler, P. (2019). Early informal STEM experiences and STEM identity: The importance of talking science. *Science Education, 103*, 623-637. doi:10.1002/sce.21499

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., and Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*, 103-120. doi:10.1002/j.2168-9830.2005.tb00832.x

Eccles, J. S., and Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53*, 109–132. doi:10.1146/annurev.psych.53.100901.135153.

English, L.D., and King, D.T. (2015). STEM learning through engineering design: fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, *2*, 1-18. doi:10.1186/s40594-015-0027-7

Ertl, B., Luttenberger, S., and Paechter, M. (2017). The impact of gender stereotypes on the self-concept of female students in STEM subjects with an under-representation of females. *Frontiers in Psychology, 8*: 703. doi:10.3389/fpsyg.2017.00703

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., and Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*, 1081-1110. doi:10.1002/tea.20040

Fraser, S., Beswick, K., & Crowley, S. (2019). Responding to the demands of the STEM education agenda: The experiences of primary and secondary teachers from rural, regional and remote Australia. *Journal of Research in STEM Education, 5*(1), 40-59. doi:https://doi.org/10.51355/jstem.2019.62

Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal, 4*, 123-143. doi:10.1080/10400419109534381

Gómez Puente, S. M., Van Eijck, M., & Jochems, W. (2014). Exploring the effects of design-based learning characteristics on teachers and students. *International Journal of Engineering Education, 30*(4), 916-928.

Goodpaster, K. P., Adedokun, O. A., & Weaver, G. C. (2012). Teachers' perceptions of rural STEM teaching: Implications for rural teacher retention. *Rural Educator, 33*(3), 9-22.

Gonzalez, H. B., and Kuenzi, J. J. (2012, August). *Science, technology, engineering, and mathematics (STEM) education: A primer*. Washington, DC: Congressional Research Service, Library of Congress. Retrieved

October 8, 2021 from http://steamwise.io/docs/congressional-research-service-R42642.pdf

Han, J., Kelley, T., & Knowles, J. G. (2021). Factors Influencing Student STEM Learning: Self-Efficacy and Outcome Expectancy, 21st Century Skills, and Career Awareness. *Journal for STEM Education Research*, 4, 117-137. doi:10.1007/s41979-021-00053-3

Hand, S., Rice, L., and Greenlee, E. (2017). Exploring teachers' and students' gender role bias and students' confidence in STEM fields. *Social Psychology of Education, 20*, 929-945. doi:10.1007/s11218-017-9408-8

Hall, C., Dickerson, J., Batts, D., Kauffmann, P., and Bosse, M. (2011). Are We Missing Opportunities to Encourage Interest in STEM Fields? *Journal of Technology Education, 23*(1), 32-46.

Haron, H. N., Kamaruddin, S. A., Harun, H., Abas, H., and Salim, K. R. (2019). Science, Technology, Engineering and Mathematics Initiatives at Rural Schools and Its Impact on Learning Motivation. *Journal of Physics: Conference Series, 1174*. doi:10.1088/1742-6596/1174/1/012002

Harris, R. S., and Hodges, C. B. (2018). STEM Education in Rural Schools: Implications of Untapped Potential. *National Youth-At-Risk Journal, 3*, 3-12.

International Technology and Engineering Educators Association [ITEEA]. (2020). *Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education*. VA: Author.

Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology, 25*, 284-301. doi:10.1007/s10956-015-9593-1

Katehi, L., Pearson, G., and Feder, M. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington, DC: National Academies Press.

Kelley, T. R. & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11). doi:10.1186/s40594-016-0046-z

Kind, P., Jones, K., and Barmby, P. (2007). Developing attitudes towards science measures. *International Journal of Science Education, 29*, 871–893. doi:10.1080/09500690600909091

Kulturel-Konak, S., D'Allegro, M. L., and Dickinson, S. (2011). Review of gender differences in learning styles: *Suggestions for STEM education. Contemporary Issues in Education Research (CIER), 4*, 9-18. doi:10.19030/cier.v4i3.4116

Lavalley, M. (2018). *Out of the loop: Rural schools are largely left out of research and policy discussions, exacerbating poverty, inequity, and isolation*. Alexandria, VA: The Center for Public Education. Retrieved from https://education.wsu.edu/documents/2018/12/center-public-education-rural-schools-report.pdf/

Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, J. P. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of Technology and Design Education, 8(1)*, doi:10.1186/s40594-020-00258-9.

Lin, K. Y., Yu, K. C., Hsiao, H. S., Chu, Y. H., Chang, Y. S., and Chien, Y. H. (2015). Design of an assessment system for collaborative problem solving in STEM education. *Journal of Computers in Education*, *2*, 301-322. doi:10.1007/s40692-015-0038-x

Makarova, E., Aeschlimann, B., and Herzog, W. (2019). The gender gap in STEM fields: The impact of the gender stereotype of math and science on secondary students' career aspirations. *Frontiers in Education, 4:60*. doi:10.3389/feduc.2019.00060

Maltese, A. V., and Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science education, 95*, 877-907. doi:10.1080/09500690902792385

Mau, W. C. J., and Li, J. (2018). Factors influencing STEM career aspirations of underrepresented high school students. *The Career Development Quarterly, 66*, 246-258. doi:10.1002/cdq.12146

Merayo, N., & Ayuso, A. (2023). Analysis of barriers, supports and gender gap in the choice of STEM studies in secondary education. *International Journal of Technology and Design Education, 33*(4), 1471-1498. doi:10.1007/s10798-022-09776-9

Mutambara, D., & Bayaga, A. (2021). Determinants of mobile learning acceptance for STEM education in rural areas. *Computers & Education, 160*, 104010. doi:10.1016/j.compedu.2020.104010

National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press. doi:10.17226/12635.

National Research Council. 2010. *Exploring the Intersection of Science Education and 21st Century Skills: A Workshop Summary*. Washington, DC: The National Academies Press. doi:10.17226/12771.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in Science, Technology, Engineering, and Mathematics*. Washington, DC: The National Academies Press. doi: 10.17226/13158

Osborne, J., Simon, S., and Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education, 25*, 1049–1079. doi:10.1080/0950069032000032199

O'Dea, R. E., Lagisz, M., Jennions, M. D., and Nakagawa, S. (2018). Gender differences in individual variation in academic grades fail to fit expected

patterns for STEM. *Nature Communications, 9*, 1-8. doi:10.1038/s41467-018-06292-0
Phothong, W., Chaimongkol, J., & Ladachart, L. (2023). Changes in Students' Design-Thinking Mindsets after Design-Based Learning with Respect to Gender and Prior Experiences in Design. *Journal of Technology Education*, *34*(2), 4-21.
Popa, R. A., and Ciascai, L. (2017). Students' Attitude towards STEM Education. *Acta Didactica Napocensia,* 10, 55-62.
Raat, J. H., and de Vries, M. (1985). *What do 13-year old students think about technology? The conception of and the attitude towards technology of 13-year old girls and boys.* The Netherlands: Eindhoven University of Technology.
Raudenbush, S. & Bryk, A. (2002). *Hierarchical linear models: Applications and data analysis methods*. Thousand Oaks, CA: Sage Publications.
Riskowski, J. L., Todd, C. D., Wee, B., Dark, M., and Harbor, J. (2009). Exploring the effectiveness of an interdisciplinary water resources engineering module in an eighth grade science course. *International Journal of Engineering Education, 25*, 181-195.
Sadler, P. M., Sonnert, G., Hazari, Z., and Tai, R. (2012). Stability and volatility of STEM career interest in high school: A gender study. *Science Education, 96*, 411-427. doi:10.1002/sce.21007
Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*, 20–26.
Shanta, S., and Wells, J. G. (2020). T/E design based learning: assessing student critical thinking and problem solving abilities. *International Journal of Technology and Design Education*, 1-19. doi:10.1007/s10798-020-09608-8
Shin, J., Lee, H., McCarthy-Donovan, A., Hwang, H., Yim, S., and Seo, E. (2015). Home and motivational factors related to science-career pursuit: Gender differences and gender similarities. *International Journal of Science Education*, *37*, 1478-1503. doi:10.1080/09500693.2015.1042941
Showalter, D., Klein, R., Johnson, J., and Hartman, S. L. (2017). *Why Rural Matters 2015-2016: Understanding the Changing Landscape*. Washington, DC: Rural School and Community Trust.
Simpson, A., and Bouhafa, Y. (2020). Youths' and adults' identity in STEM: A systematic literature review. *Journal for STEM Education Research, 3*, 167-194. doi:10.1007/s41979-020-00034-y
Simpson, A., Collazo, J. M., Zilvinskis, J., and Maltese, A. (2021). Professionals' identification within and across science, technology, engineering, and mathematics (STEM) fields. *Journal of Career Development, 48*, 942-956. doi:10.1177/0894845320913112
Sırakaya, M., Alsancak Sırakaya, D., and Korkmaz, Ö. (2020). The impact of STEM attitude and thinking style on computational thinking determined via

structural equation modeling. *Journal of Science Education and Technology, 29*, 561-572. doi:10.1007/s10956-020-09836-6

Suárez, M. I., and Wright, K. B. (2019). Investigating School Climate and School Leadership Factors that Impact Secondary STEM Teacher Retention. *Journal for STEM Education Research, 2,* 55-74. doi:10.1007/s41979-019-00012-z

Swafford, M., & Anderson, R. (2020). Addressing the Gender Gap: Women's Perceived Barriers to Pursuing STEM Careers. *Journal of Research in Technical Careers, 4*(1), 61-74.

Svenningsson, J., Hultén, M., and Hallström, J. (2018). Understanding attitude measurement: Exploring meaning and use of the PATT short questionnaire. *International Journal of Technology and Design Education, 28*, 67-83. doi:10.1007/s10798-016-9392-x

Talafian, H., Moy, M.K., Woodard, M.A., and Foster, A.N. (2019). STEM identity exploration through an immersive learning environment. *Journal for STEM Education Research* **2,** 105–127. https://doi-org.ezproxy.lib.purdue.edu/10.1007/s41979-019-00018-7

Taylor, M., Jonathan M. T., Hollie M. C., and Lorelle L. E. (2020). *Race and ethnicity in higher education: 2020 supplement*. Washington, DC: American Council on Education.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... and Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education, 3*: 02. doi:10.20897/ejsteme/85525

Tseng, K. H., Chang, C. C., Lou, S. J., and Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education, 23,* 87-102. doi:10.1007/s10798-011-9160-x

Tyler-Wood, T., Ellison, A., Lim, O., and Periathiruvadi, S. (2012). Bringing up girls in science (BUGS): The effectiveness of an afterschool environmental science program for increasing female students' interest in science careers. *Journal of Science Education and Technology, 21,* 46-55. https://doi.org.ezproxy.lib.purdue.edu/10.1007/s10956-011-9279-2

Unfried, A., Faber, M., and Wiebe, E. N. (2014, June). *Student Interest in Engineering and Other STEM Careers: School-Level, Gender, Race/Ethnicity, and Urbanicity*. In 2014 ASEE Annual Conference and Exposition (pp. 24.1114.1-24.1114.27).

Unfried, A., Faber, M., Stanhope, D. S., and Wiebe, E. (2015). The development and validation of a measure of student attitudes toward science, technology, engineering, and math (S-STEM). *Journal of Psychoeducational Assessment*, 33, 622-639. doi:10.1177/0734282915571160 van den Hurk, A., Meelissen, M., and van Langen, A. (2018). Interventions in education to prevent STEM pipeline leakage. *International Journal of Science Education, 41*, 150-164. doi:10.1080/09500693.2018.1540897

van der Vleuten, M., Steinmetz, S., and van de Werfhorst, H. (2018). Gender norms and STEM: the importance of friends for stopping leakage from the STEM pipeline. *Educational Research and Evaluation, 24*, 417-436. doi:10.1080/13803611.2019.1589525

van Tuijl, C., & van der Molen, J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education*, *26*(2), 159-183. doi:10.1007/s10798-015-9308-1

Yaşar, Ş., Baker, D., Robinson-Kurpius, S., Krause, S., and Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education*, *95*, 205-216. doi:10.1002/j.2168-9830.2006.tb00893.x

Xie, Y., Fang, M., and Shauman, K. (2015). STEM education. *Annual review of sociology, 41*: 331. doi:10.1146/annurev-soc-071312-145659

Wahono, B., and Chang, C. Y. (2019). Assessing teacher’s attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education. *Sustainability, 11*: 950. doi: 10.3390/su11040950

Wang, M. T., Ye, F., & Degol, J. L. (2017). Who chooses STEM careers? Using a relative cognitive strength and interest model to predict careers in science, technology, engineering, and mathematics. *Journal of Youth and Adolescence*, *46*, 1805-1820. doi:10.1007/s10964-016-0618-8

Wang, T.-L., and Berlin, D. (2010). Construction and validation of an instrument to measure Taiwanese elementary students’ attitudes toward their science class. *International Journal of Science Education, 32*, 2413-2428. doi:10.1080/09500690903431561

Wegemer, C. M., and Eccles, J. S. (2019). Gendered STEM career choices: Altruistic values, beliefs, and identity. *Journal of Vocational Behavior, 110*, 28-42. doi:10.1016/j.jvb.2018.10.020

Wells, J. G., (2021). Design based biotechnological learning: Distinct knowledge forms supporting technology and science conceptual understanding, Chapter 11, pp. 223-247 in Ineke Henze and Marc J. de Vries (Eds.), *Design-based concept learning in science and technology education*. Sense/Brill, International Technology Education Studies, Leiden, The Netherlands. https://doi.org/10.1163/9789004450004_011

Wells, J. G., (2016b). Efficacy of the technological/engineering design approach: Imposed cognitive demands within design based biotechnology instruction. *Journal of Technology Education, 27*(2), 4-20.

Wells, J. G., (2016a). Integrative STEM Education Exemplar: Implementation of the PIRPOSAL Model. *Technology and Engineering Teacher, 75*(10), 16-23.

Wells, J. G. (2013). Integrative STEM Education at Virginia Tech: Graduate preparation for tomorrow's leaders. *Technology and Engineering Teacher*, *72*(5), 28-35. Reston, VA

Woolfolk, A. E. (2019). *Educational psychology (14th ed.)*. New York, NY:Pearson.

Zarifa, D., Seward, B., and Milian, R. P. (2019). Location, location, location: Examining the rural-urban skills gap in Canada. *Journal of Rural Studies, 72*, 252-263. doi:10.1016/j.jrurstud.2019.10.032

About the Authors

Euisuk Sung (esung@citytech.cuny.edu) is an Assistant Professor in Career and Technology Education at New York City College of Technology, City University of New York. https://orcid.org/0000-0001-7162-875x

Jung Han (han336@purdue.edu) is a post-doctoral researcher in Engineering Technology Teacher Education at Purdue University in West Lafayette, IN. https://orcid.org/0000-0003-0569-1552

Todd R. Kelley (trkelley@purdue.edu) is a Professor in Engineering Technology Teacher Education at Purdue University in West Lafayette, IN. https://orcid.org/0000-0001-6086-1927