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EDITORIAL

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As we close another year in STEM education, the December 2024 issue of the Journal of Research in STEM Education (J-STEM) presents four groundbreaking studies that highlight the evolving landscape of STEM and STEAM education. These contributions reflect the diversity of approaches, the importance of self-efficacy in engineering and STEM learning, and the critical role of educators in fostering future-ready skills.

In "The Development and Validation of the Children's Engineering Self-Efficacy Scale (CESES)," Amy Catalano addresses a crucial gap in the literature by developing an instrument to measure children's engineering self-efficacy. With growing emphasis on engineering design in K-12 curricula, this study not only highlights the role of self-efficacy in fostering problem-solving and innovation but also provides a robust tool for evaluating the effectiveness of STEM interventions. The implications of this research extend to both formal and informal learning environments, reinforcing the importance of self-belief in shaping young learners' engagement with STEM disciplines.

Stuart Kent White and Timothy J. Newbya's contribution, "Exploring Pre-Service Elementary Educator Anxiety for Facilitating Science Teaching Contexts Integrating 3D Modeling," shifts the focus to teacher preparation and the role of technology in reducing instructional anxiety. By examining the use of Tinkercad, a 3D modeling software, within pre-service teacher programs, the study reveals that while such tools help alleviate anxiety, their effectiveness in enhancing self-efficacy and teaching competence remains limited. This underscores the need for holistic professional development programs that not only introduce technological tools but also provide sustained pedagogical support for integrated STEM education.

"Exploring Evolving Perspectives: Research Trends in Attitudes toward STEAM Education" offers a meta-perspective on the field's rapid evolution. By analyzing publications from 2020 to 2024, this study identifies key trends, including the rising contributions from Spain, Taiwan, and Turkey, alongside continued leadership from the USA, China, and Jordan. A significant takeaway is the increasing focus on educators' attitudes toward STEAM, reflecting a shift in research priorities towards teacher readiness and pedagogical practices. This comprehensive review serves as a valuable resource for researchers and policymakers aiming to understand the global trajectory of STEAM education.

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"Broadening Perspectives of STEM Education: A New Conceptual Framework" by Anwar Rumjaun and colleagues offers a critical synthesis of existing STEM frameworks. Drawing from diverse global contexts, the authors propose a new conceptual model that integrates epistemological, psychological, and didactical dimensions of STEM education. This work addresses the need for cohesive policies and practices that reflect the interdisciplinary nature of STEM, emphasizing the importance of aligning educational goals with broader societal challenges.

The final paper, "Supporting BIPOC Males in STEM: Insights from a Case Study on Online Peer Mentoring" by Jillian Wendt and Vivian Jones, provides an in-depth look at the role of online peer mentoring in fostering self-efficacy, belonging, and retention among BIPOC male students at HBCUs. By exploring the lived experiences of these students, the study identifies key themes of identity formation, increased confidence, and the drive to make an impact, reinforcing the importance of culturally responsive mentoring initiatives in supporting underrepresented populations in STEM fields.

As we look ahead, the insights provided in this issue reinforce the necessity of fostering self-efficacy, reducing instructional barriers, and reimagining STEM education through interdisciplinary frameworks. We are proud to announce that J-STEM is in the process of applying for index inclusion, a significant step towards expanding the journal's reach and impact. With a strengthened editorial team and enriched vision for 2025, we are excited to continue supporting innovative research and contributing to the global STEM education discourse.

We extend our deepest gratitude to the authors, reviewers, and the entire editorial board for their unwavering dedication to advancing STEM education research.

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RESEARCH REPORT

The Development and Validation of the Children's Engineering Self-Efficacy Scale (CESES)

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Abstract
In order to best prepare future generations to solve societal challenges, students should be provided with a foundation in problem solving skills. Accordingly, the Next Generation Science Standards (NGSS) incorporates engineering design process skills along with the scientific practices. While engineering curriculum opportunities have expanded, research testing the efficacy of engineering design instruction on problem solving skills is limited. Self-efficacy research has long drawn connections of high science self-efficacy to improved attitudes and performance. However, little research has examined engineering design self-efficacy, and none has been conducted with children. This study reports the development and validation of the Children's Engineering Self-Efficacy Scale (CESES). Participants included 212 children in grades 3-7 from a variety of instructional backgrounds. Initial results showed that the instrument produced a Cronbach's alpha of .81. Factor analysis resulted in a five-factor model explaining 56.72 % of the variance. Additional analyses showed that the majority of participants had good to high engineering self-efficacy. The result of this research has implications for examining the growth of self-efficacy after STEM or engineering interventions both in school programs and in out-of-school programs.

Keywords: *Engineering design process, Self-efficacy, STEM education, surveys and questionnaires, scale validation*

The ability to problem solves is an integral life and academic skill. In the last decade educational reform has emphasized the development of 21st century skills, which are the skills modern students require to function effectively in a technologically based society (Larson & Miller, 2011; National Science Teacher Association [NSTA], 2011). Twenty-first century skills include media and digital literacy, creative thinking and problem solving, among other skills. Accordingly, the Next Generation Science Standards (NGSS) emphasize these skills with the inclusion of the engineering design practices (NSTA, 2011). "Providing students a foundation in

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engineering design allows them to better engage in and aspire to solve the major societal and environmental challenges they will face in the decades ahead" (NGSS, 2013, Appendix I). Further, the Standards for Technological and Engineering Literacy (STEL; (International Technology and Engineering Educators Association [ITEEA], 2020) explicitly call for the integration of engineering practices within other content areas. The STEL were developed based on the 21st Century skills and the Engineering Habits of Mind, which include systems thinking, problem-finding, visualizing, improving, creative problem-solving and adapting. In the science classroom, children are increasingly being asked to define problems, design solutions, develop models, apply computational thinking, collaborate with others, and communicate solutions.

While the terms science, STEM and engineering tend to be used interchangeably in the field of education, STEM education is defined as the integration of the knowledge and skills of two or more STEM disciplines applied to a real-world problem (English, 2016). Similarly, engineering education focuses on developing the engineering design process (EDP) skills within the science curriculum (and increasingly among other disciplines including math and art). The ITAAE (2020) more specifically delineates the difference as an emphasis on "technological products, design, and technology/society interactions…and the use of engineering design and application of engineering habits of mind…" (p. 5). While several models of the EDP exists for different age groups, the model generally includes determining the problem to be addressed, defining the constraints and requirements, researching and brainstorming ideas, planning (and drawing models), building, then testing, and then working with other "engineers" to improve the design. In addition to being an integral part of engineering education, the EDP also supports student development of problem-solving skills (NSTA, 2011). Given that the NGSS asks students to demonstrate the science and engineering practices, this article focuses on the EDP which most closely aligns with those practices.

Self-efficacy has long been linked to achievement and other desirable outcomes (Larson et al., 2015). Assessing self-efficacy so that it can be improved through curricular interventions is necessary to improving student outcomes in engineering and STEM education. While there are scales for adults to measure engineering self-efficacy and for children there are STEM self-efficacy measures, presently there are no assessments of engineering self-efficacy for children. To address this gap in measurement, this article reports the development and validation of the Children's Engineering Self-Efficacy Scale (CESES). This scale is based on the elements of the EDP and assesses the degree to which students are confident in their abilities to engage with all steps of the EDP including planning, problem solving, improving solutions, and working with others to improve a design. This article also describes differences among various subgroups on the CESES.

The Role of Self-efficacy in Engineering Education

People develop beliefs about their own self-efficacy by interpreting and synthesizing multiple sources of information about their abilities (Pfitzner-Eden, 2016). Bandura's (1997) sources of information self-efficacy include mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states, although mastery experiences have the most significant contribution to self-efficacy.

As noted previously, self-efficacy has been correlated with improved educational outcomes including graduation rates, career choice, engagement, and effort (Larson et al., 2015; Ponton et al., 2001; Webb-Williams, 2018). Science self-efficacy has been examined for its impact among groups including teachers and girls. Previous research showed that higher self-efficacy for science teaching demonstrated increased time spent teaching science, responsiveness to students, motivation to teach more creatively and to try new methods (Utley et al., 2019). Research on pre-service teachers has also revealed that exposure to engineering design can significantly improve engineering pedagogical content knowledge and self-efficacy (Perkins Coppola, 2019; Yesilhurt et al., 2021).

With respect to STEM education, Bandura et al (2012) examined the role of self-efficacy beliefs on children's career paths among over 270 children. Children's perception of their efficacy and academic self-efficacy, rather than their academic achievement, was a major predictor of perceived occupational self-efficacy, in other words, their ability to do well in particular careers. Importantly, gender differences showed that male students had higher math self-efficacy and female students had higher language self-efficacy. Given the relationship between self-efficacy and career choices, these results have major implications for steering women into STEM based fields. Other researchers have also linked self-efficacy to career participation (see for example, Caspi et al, 2019; Caspi et al, 2020; Conradty et al., 2020).

Research from the Boston Children's Museum, developers of the Engineering is Elementary program, has shown the positive impact of engineering curriculum on children's science learning and problem-solving skills (Cunningham et al., 2019). Research on children's self-efficacy in STEM or science has examined children's perceived confidence in science and math and how it impacts constructs such as career choice and performance (Bandura et al, 2001; Betz & Hackett, 2000). A great deal of research on teacher's self-efficacy in STEM and engineering has been produced. And it is certainly the case that teacher self-efficacy impacts students' performance. For example, a meta-analysis conducted by Menon et al. (2024) showed that that gains in teacher self-efficacy in STEM and engineering are limited. However, no research has been conducted on children's self-efficacy in engineering design. Given the relationship between self-efficacy, achievement, and other outcomes assessing and intervening to improve, engineering design self-efficacy is a necessary element to facilitating the success of engineering design curriculum.

Existing Scales of Self-Efficacy and Engineering

Much research on self-efficacy and engineering examines the impact of teacher self-efficacy on student efficacy because teacher efficacy can predict teaching behaviors. For example, Yoon et al. (2014) developed a scale to assess teacher self-efficacy to teach engineering design. Items on the scale primarily dealt with teacher confidence to teach engineering with statement such as "When students do better than usual in engineering, it is often because I exerted a little extra effort" (p. 484). Hammack and Ivey (2017) also examined teacher engineering self-efficacy (ESE) and found that they largely had low engineering design self-efficacy in addition to having low self-efficacy for pedagogical content knowledge related to engineering design. These results are unsurprising and point to the need for significant efforts to offer professional development to promote knowledge and confidence to teach children engineering.

Self-efficacy scales developed for engineering students are limited to adolescents and adults. Amato-Henderson et al. (2007) developed the Longitudinal Assessment of Engineering Self-Efficacy for middle and high school students. The scale contains statements about students' perceptions of success in their engineering classes and those around them as well as their opportunities for advancement in engineering in the future. The authors found that while the engineering event around which the study was based did not improve self-efficacy in engineering, knowing an engineer did significantly contribute to positive self-efficacy. This drives home the value of having access to a role model who is participating in the STEM workforce.

Carberry et al. (2010) developed the engineering self-efficacy scale for adults ages 20-62. Like the present study, they sought to evaluate ESE by examining participant's confidence and motivation to participate in each step of the EDP including identifying a design need, developing solutions, selecting the best design, constructing a prototype, testing and communicating a design, and then redesigning (improving). They found that self-efficacy in engineering was highly correlated to outcome expectancy and motivation and negatively correlated to anxiety.

While the above is sampling of available engineering self-efficacy scales, they are limited in utility for the present study for several reasons. Carberry's (2010) scale was designed for adults but used language most like the scale developed for the current study in that participants are asked to rate their confidence in doing specific engineering design tasks, such as formulating questions. Yoon et al (2020) explicitly ask teachers to rate their confidence to teach engineering as opposed to the specific engineering design tasks. One notable gap in the literature is the lack of assessment as to whether participant's self-efficacy is correlated to their actual knowledge or abilities. While this later concept is not explored in the current study, it emerges as a method of convergent validity.

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STEM Self-Efficacy

Although scales for measuring children's self-efficacy for participating in the EDP are lacking, several scales have been developed to measure STEM self-efficacy. The Activation Lab (2019) has developed a variety of measures to assess children's and adolescent's affective domains as they relate to science and STEM. Most salient to the current study is the competency beliefs in STEM survey, which provides statements asking participants to rate their level of agreement about their abilities to read science texts, solve math problems and engage in technology. These surveys were developed for students in grades 5 and above and do not address the EDP as discussed further in the methods section.

Luo et al. (2021) recently published findings on their STEM self-efficacy scale developed for 844 primary school children in grades 4-6. The scale was developed to assess self-efficacy to complete STEM activities. Many of the items on the scale are closely aligned with the EDP; examples include "I am able to define the problem to be solved...I am able to design solutions to the problem." (p. 414). The scale had a CA of .90 with a single factor structure. Analysis of their findings showed that participating in school and out-of-school STEM activities significantly predicted SE in STEM, while age and gender did not.

This review of research makes it clear that there is an established need to assess ESE among children who are now being introduced to engineering design process skills via the NGSS. No published studies have described a scale suitable use for children that assesses self-efficacy in using the engineering design process. If children and youth will be expected to demonstrate these skills, evaluating their ability, knowledge of, and self-efficacy is integral to assessing curricular effectiveness and other interventions. Accordingly, the following section describes the development and validation of the CESES.

Methods

Participants

Participants were students in a variety of educational settings in which an engineering design program was implemented. A total of 263 surveys were collected as some participants took both a pre and post-test. A total of 212 of those surveys, which were only post-tests, were used for the reliability and validity evaluation. Of those 212 participants, 144 were girls and 68 were boys. There were more girls than boys because 81 participants were in grades 3-8 attending a four-week Summer STEM program for girls.

Participants also included 131 students who were taught four-week long engineering design units during the regular school day. Twenty-one of these students were from a gifted school. Four children were designated as students with learning disabilities. Most students were in 6th grade (n = 130), 24 were in 3rd, 9 were in 4th, 33 were in 5th and 16 were in 7th grade.

All students were taught engineering design units in which the culminating project was engineering design challenge. All students were taught the engineering design process through the unit. Children in the summer program were taught two short units and children in school were taught one longer unit; however, all instruction was four weeks long. Most participants attended public schools in Nassau County, Long Island in New York State. However, one small group of students were 5th graders in a private gifted and talented school. Two instructors taught in the summer program, and six taught in the regular school program. All instructors were graduates of a master's degree program in elementary STEM education and were certified elementary school teachers. These instructors took courses on children's engineering, STEM curriculum design and produced master's thesis implementing engineering curriculum.

While some groups of students received the questionnaire as both a pre and post-test to an engineering curriculum intervention, only post-test data were used for the reliability tests and factor analysis because not all children took both a pre and post-test. Because the scale was administered in different scenarios, via a summer program, a regular school setting, and in a gifted school, some children were not present for the administration of the posttest. The researcher decided to use the post-test rather than pre-test because all students would have been exposed to engineering design vocabulary and concepts. A limitation of this approach is that all students received training in engineering design and were likely more self-efficacious than children who did not receive such training, as is further explained below regarding the development of the scale. Two hundred and twelve students took a post-test. Post test data were also used to compare performance on the CESES among genders, school type (summer vs. regular), and grade levels.

Development and content validation of the CESES

The development of the initial scale began with a review of published scales on children's self-efficacy in STEM, science and math. In addition, existing scales on ESE for older participants were examined. The Engineering Design Self-Efficacy Instrument developed by Carberry et al (2010) was designed for adults and was validated with participants ages 20-62. The questionnaire includes 17 statements, three of which are negatively phrased. The items were based on the eight-step model of the EDP developed by the Massachusetts Department of Education (2001/2006). Participants in Carberry's study were asked to rate their level of anxiety, confidence, and motivation to do each listed engineering task (e.g., research a design need, communicate a design, and redesign). While Carberry et al.'s scale was conceptually closest to the CESES, other scales written for children provided a more relevant framework for the development of the items.

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Accordingly, the STEM competency beliefs scale by Activation lab (2019) provided the basis for the structure of the statements. The statements themselves were designed to follow the engineering design process as presented in the Engineering is Elementary curriculum (EIE.org, 2020). The items were designed to assess the following phases of the EDP: ask (asking questions), imagine (brainstorm), plan (with a detailed sketch), create (build) and improve (test, consult with other engineers, and improve the design, and test again). Because the EDP is designed to be conducted collaboratively, several items included the phrase "…when working with others…"

Bandura's (1997) sources of self-efficacy served as the conceptual basis for developing the items. Because mastery experiences are the biggest contributors to self-efficacy, the phrasing of the items focused on a participants' confidence in engaging in a part of the engineering design process. Most of the items in the CESES begin with the phrase "When given a design challenge, I can…" The survey is divided into two parts to allow students space to pause and think between two groups of items. The statements fall into the following categories that represent the EDP as described above: confidence in solving problems, knowing which questions to ask, knowing when and how to draw a plan of their ideas, working with others, knowing that failing and improving is part of the process, knowing how to apply constraints and requirements. Two negatively phrased items were included in this scale. Negatively phrased items are included in scales to mitigate response bias, particularly salient when assessing children as they are more likely to acquiesce with positively phrased statements for social acceptability reasons. The inclusion of the negatively phrased items allowed participants to consider the concept being assessed through a rephrasing. In addition, negatively phrased items are often included in scale development to inhibit participants from reading the statements too quickly and responding positively to each item.

The first version of the questionnaire included a scenario about being asked to develop a solution for designing a roller coaster for an amusement park. The scenario was then followed by questions intended to determine whether students were able to do the task for which they reported self-efficacy. However, this section made the scale difficult to score as the questions needed to be open-ended. Future revisions or predictive validity assessments might include this type of scenario.

Because the scale is intended to assess self-efficacy of specific engineering skills, children may not be familiar with many of the vocabulary words until they have received instruction on the engineering design process and/or completed at least one challenge. It is recommended that for pre-post testing, that the pre-test be given after one brief challenge or after students have been taught the EDP. Students should then be post-tested after the established curriculum is presented to measure growth. Pre-testing prior to any instruction may fail to capture whether a child has low self-efficacy or does not know the vocabulary. In this study, all students had some experience

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with engineering design prior to being given the pre-test CESES. Post-test data only was used for the validation study.

Content validation

Content validity was assessed by sending the original version of the scale to an Engineering Department faculty member who is an expert in children's engineering design and teaches courses on the design of engineering curriculum for children. This expert also recommended the inclusion of the scenario but agreed that its inclusion took away from the intent of the scale to measure SE only. This faculty member also recommended revisions to wording and suggested reviewing the EDP developed by the Massachusetts Department of Education (2001/2006). Additionally, another scientist working on the engineering programs Wise Guys and Girls and STEMgineering reviewed the scale. Finally, the scale was reviewed by five elementary school teachers who had graduated from a STEM Master's degree program, who had all written engineering design curriculum and conducted a related study for their theses. Revisions to wording was made based on this feedback. The items from resulting from these efforts appear in the results section of this article.

Data collection procedures

The survey was administered before and after the following STEM interventions. The first STEM intervention was a summer STEM program for girls in grades 3-7. The program was four weeks long, two days a week for half days. Students engaged in two engineering design units with design challenges including electrical engineering, biotechnology engineering, designing race cars, and designing prosthetics for animals. All units involved learning science content needed to address the engineering design challenge. The last two lessons of each unit focused on planning and designing a solution to the challenge, then testing, improving and receiving feedback from other "engineers". The study was conducted over two years, so each year participants engaged in different design challenges. For girls who participated both years, only their post-test (2nd) survey was used in this study. Students were read the survey allowed and instructors noted which students had difficulty completing the survey.

For the 131 students who completed the CESES during in-school programs, all were exposed to instruction on the EDP and had experience completing small engineering design challenges such as building towers using index cards prior to taking the survey. All students were then taught an 8-lesson science unit that culminated in an engineering design challenge. Unit topics included designing an ecosystem for a particular animal, designing a new planet under specific conditions, designing a constellation, and designing housing to withstand extreme weather.

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Results

Reliability

To assess the psychometric properties of the CESES, 212 post-tests were analyzed. To determine the internal consistency and reliability of the scale, a Cronbach's alpha .81 was derived for the 17 items scale, indicating good reliability (Hair et al., 1998). Alphas for all items ranged from .791 to .826.

Construct validity

A principal components analysis with Varimax rotation was conducted to determine construct validity and variance explained. Varimax rotation was employed as it maximizes variance and is useful in analyzing multiple latent variables that are not correlated (Dilbeck, 2017). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .841 and Bartlett's Test of Sphericity was significant at $p < .001$ with a value of 840.812; both measures indicated that the data were suitable for factor analysis.

Table 1.

Rotated component matrix and factor loadings

	Factor				
	1	2	3	4	5
Q9	.724	.066	-.042	.057	-.142
Q12	.653	.133	.064	.091	.167
Q11	.619	.364	-.009	.070	.175
Q1	.616	-.006	.237	.023	-.192
Q13	.600	.178	.052	.120	.247
Q2	.581	.117	.104	.204	.013
Q8	.515	-.182	.283	.404	-.021
Q7	.453	.386	.434	.162	-.079
Q10	.432	.246	.366	.170	-.402
Q4	.198	.799	-.082	.146	.034
Q5	.129	.774	.247	.177	-.068
Q15	.001	.181	.694	-.172	.269
Q6	.186	-.065	.693	.234	.139
Q3	.121	.163	.118	.748	.100
Q17	.186	.202	-.047	.732	-.033
Q14	.218	.011	.080	-.039	.736
Q16	-.106	-.011	.224	.131	.628

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Five factors with an Eigen value greater than 1.0 emerged from these analyses. This five-factor model represented a combined variance of 56.72%. All but two items loaded on distinct factors at loadings greater than .454, with most factors loading at .6 and above. Items 7 and 10, loaded between .4 and .5 and loaded on several other components at the .2-= to .3 range. Both questions referred to improving a design and conceptually belong to the factor one which articulates several steps of the EDP. Removing these two items resulted in a four-factor model, in which the variance explained decreased to 51.81 and reliability decreased to .77. To maintain reliability, the 5-factor model was retained (Table 1). See Table 2 for the list of items, with loadings for each factor.

Table 2.
Five factor model with items statements arranged by factor

Factor	Eigenvalue	Total variance	Item number	Item
1.Problem solving and asking questions	4.67	27.468	1	I am good at solving problems
			2	When given a design challenge, I know which questions to ask in order to get started
		Low loading	7	If my design doesn't work well the first time, I can improve it and test it again
			8	I can ask other classmates for their advice on my design
			9	I am good at coming up with new ideas to solve problems
		Low loading	10	I can come up with more than one solution and pick the one that works the best.
			11	When given an engineering design challenge, I can figure out what needs to be included in the solution
			12	When given an engineering design challenge, I can create a solution using only materials given to me
			13	When given an engineering design challenge, I can create a solution in the amount of time I'm given by my teacher
2.Modeling and planning	1.54	9.069	4	When given a design challenge, I can create a model of my solution to start solving the problem
			5	When given a design challenge, I can draw a plan to solve the problem
3. Working with others	1.28	7.524	6	When given a design challenge, I am good at working with the other people in my group to come up with a solution
			15	I don't think it's helpful to ask other classmates for their feedback

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Factor	Eigenvalue	Total variance	Item number	Item
4.Brainstorming	1.04	6.134	3	When given a design challenge, I first think about how I can solve the problem before I start building
			17	When I'm given a design challenge, I do some research first
5.Lack of improving and planning	1.03	6.039	14	When my design doesn't work the first time, I don't feel like finishing the project
			16	When I'm given a design challenge, I start building right away

EDP Self-Efficacy Scores

To examine differences between groups, the total sample of 212 post-tests were used. The mean score for all participants was 53.8 and the standard deviation was 6.94. The range of scores was between 33-68 (Table 3). To allow researchers to determine the strength of self-efficacy among children, cut off scores were derived using standard deviations. The minimum possible score was 17 and the maximum score was 68. Since the mean score was 53.7, the average scale rating for each item was 3 points, indicating that all participants had reasonable self-efficacy after the post test. These cutoff scores are only a guideline and based on this sample's performance. Other researchers may wish to use the raw scores for other types of analyses. Because many of the participants in this study had been exposed to engineering curriculum previously and were taught by trained STEM teachers, the scores reported in this study may be higher than typical.

Table 3.
Cutoff scores for ESE

Score range	Category	Number of participants scoring	Percent
61-68	high ESE	43	20.3
53-60	average to good ESE	86	40.4
45-52	average to low ESE	58	27.2
17-44	low ESE	25	11.8

These score ranges demonstrate that most participants were average/good too high in ESE. These higher scores make sense in the context of the students' exposure to other STEM interventions including the summer program and the fact that all instructors in the study were trained in engineering design instruction.

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Differences between genders on engineering self-efficacy

Several Analysis of Variance (ANOVAs) tests were performed to determine whether there were significant differences between various groups on the CESES. In the use of an ANOVA there is an assumption that variances among groups within a population are equal. Because subgroups within the sample varied, a Levene's test for homogeneity of variance was conducted. The Levene's test was not significant at $p = .795$ indicating that the assumption of homogeneity of variance has been met. Therefore, the F tests are interpretable.

Girls demonstrated a mean score of 54.55 ($n = 144$) and boys 52.07 ($n = 68$). There was a significant difference between girls and boys (F (1, 2120 f = 5.950, $p < .01$). However, there was an uneven representation of genders in this study. Many of the participants in this study were girls, and many of those girls were attendees at the summer STEM program which focuses on engineering. Many of the girls in the summer program had been attending for 2-4 years.

Differences between grade levels on engineering self-efficacy

Differences between grade levels were also assessed given the wide distribution of grades. There was a significant difference between grades on ESE, ($F(4, 212)$ f = 2.753, $p < .05$) 5th graders ($n = 33$) had the highest mean score at 56.69, while 3rd graders had the lowest mean score at 51.62 ($n= 24$). See Table 4 for means. Post hoc analyses using a Tukey test revealed that the significant difference was between grades 3 and 5, $p < .05$. There was trending difference between grades 6 and 7, $p = .064$

Differences between summer program participants and school programs

Finally, means between students in the summer STEM program for girls and students who took the CESES during regular school programming were analyzed. Participants in the summer program scored a mean of 54.24, while those in regular school scored a mean of 53.45. These differences were not statistically significant, $p = .426$.

Table 4.
Comparison between grades on CESES

Grade	Mean	N
3	51.6250	24
4	53.8889	9
5	56.6970	33
6	53.1308	130
7	55.9375	16
Total	**53.7594**	**212**

Discussion

This study describes the development and validation of an ESE scale developed for children and young adolescents. The results demonstrate that the CESES is a valid and reliable tool that may be used to assess the self-efficacy of children and youths in grades 3-7 after participating in an engineering design unit. While the results of the factor analysis showed that the items from the five-factor model loaded onto distinct factors, these factors did not cleanly emerge from the EDP –demonstrating that the EDP skills are linked in some cases. In fact, most items in factor one related to several steps in the EDP including problem solving, asking questions and improving indicating the design process is conceptually one latent variable. The other factors were more related to the mechanics of the EDP such as impulsive decision making and working with others. For example, working collaboratively emerged as its own factor. Working collaboratively can be characteristic of all the EDPs but only emerged as its own factor in questions asking specifically about working with others. The other factors that emerged related to lack of planning and improving (impulsivity), problem solving and questioning in general, working with others, and planning and modeling. These factors make sense in the context of the science and engineering practice described in the NGSS standards. A self-efficacy scale to complete STEM activities, with items covering some aspects of the EDP, developed by Luo et al (2021) found a one factor solution for a 10-item scale.

Mastery experiences strongly predict self-efficacy (Pfitzner-Eden, 2016). Examination of the average scores among subgroups showed that participants had good to high scores. Most participants were girls who were the participants in the summer program in which they engaged in several engineering design projects. These results affirm that frequent exposure to engineering concepts, particularly improvement as an objective in the process, will increase confidence in one's abilities.

In this study most participants had average to high average scores on the CESES as indicated by the cutoff scores derived from this sample. The participants in this sample were all taught by relatively new teachers with 1-3 years of experience but trained in the design and use of engineering design challenges. All instructors graduated from an elementary education STEM Master's program in which engineering is the focus. Further, all instructors completed theses that assessed the effectiveness of a STEM (engineering design) unit. While post-test scores were used for this study, nearly all participants had been exposed to an engineering design challenge previously and so their scores may be higher than those of other children. As is a risk in many studies that include self-report, particularly among children, high scores may be a result of social desirability. This risk is another argument for validating the results with an assessment of true engineering ability and knowledge.

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Results also showed no significant differences between males and females on self-efficacy; however, many of the participants were female. These findings support those of Luo et al (2021) who did not find differences between genders on self-efficacy, but did find that participation in both in-school and out-of-school STEM experiences predicated self-efficacy in STEM. In this study no differences were found between participants in the summer program and those who were exposed to the engineering units during the school day, but what all participants had in common was exposure to at least one engineering design challenge and unit, and thus familiarity with the vocabulary.

Researchers and educators who choose to assess CESES with children who have no experience with engineering design will very likely find much lower scores. Because the vocabulary used in the CESES is discipline-specific, it is important that those administering the scale take time to expose students to the vocabulary through readings or other related activities. To preserve the validity of the scale when it is being used a pre-test, students should not have had the experience of completing and engineering design challenge previously, or at least that experience should be statistically controlled for. In addition, for true growth in content knowledge and engineering design ability and self-efficacy, meaningful instruction should focus on design challenges that solve a relevant and local problem of importance to children. Repeated exposure to engineering design challenges through a variety of disciplines will not only improve engineering self-efficacy, but also problem-solving skills.

Limitations and Recommendations for Future Research

The limitations of this study include the diversity of age and grade ranges. All grade ranges scored in the average to high realm, but there were differences among 3, 5 and 6th graders. The large number of 6th graders also may have skewed scores upwards. Future research may target a smaller age band for which this scale is appropriate. Third graders scored the lowest on this scale; this may have been a function of literacy level or less exposure to engineering design challenges. As survey taking is largely a literacy endeavor, those participants who were emergently literate may have difficulty completing the survey. The few students in this study with IEPs were read the survey aloud. Future research should include evaluating the readability of the survey for younger participants.

The study included new teachers trained in engineering design. Future research might include more experienced teachers with less engineering design training. The true usefulness of the CESES will show a baseline of where students stand in the ESE prior to introduction to the engineering curriculum. It will also show the impact of teachers with and without engineering training and professional development. Finally, the validation study only included 212 participants in one suburban area of New York State. Future research should assess the validity of this scale on children in other regions of the United States as well as internationally.

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Future research should also examine predictive and concurrent validity. Correlating the scores of the CESES against other science or STEM self-efficacy measures would better support the validity of this measure. The development of the CESES allows researchers to use the scale to assess the effectiveness of engineering curriculum and other programmatic interventions on students' ESE. Accordingly, this scale may be used as a pre and posttest in various contexts. Lastly, future research should include assessing the match between students reported self-efficacy and their actual ability as intended by the scenario included in the initial version of the scale.

Note: Please write to the author for a copy of the CESES or to obtain permission to use the scale.

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RESEARCH REPORT

Exploring Pre-Service Elementary Educator Anxiety for Facilitating Science Teaching Contexts Integrating 3D Modeling

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Abstract

Much of the research within K-12 STEM teacher education and integrated STEM instructional design (ID) involves illuminating how STEM subjects can be integrated to bridge gaps between methodological and pedagogical practices. ID involving the engineering design process within K-12 classrooms generally guides students through prototyping mechanical devices using everyday objects and/or 3D printing. One universal engineering process involved in STEM educational curriculum is modeling using computer aided design (CAD) software such as Tinkercad (a popular software in K-12 settings). This study focuses on the application of 3D modeling as a learning activity within an undergraduate biology course designed to prepare pre-service teachers to facilitate life science learning activities in their future classrooms. A mix methods approach was taken to explain the impact of Tinkercad modeling on anxiety for facilitating integrated STEM activities as well as pre-service teacher self-efficacy, confidence in, and competency for teaching integrated STEM. Analysis of student responses to survey questions, field notes, and informal interviews suggest that utilization of modeling software divorced of 3D printing, though conducive to reducing integrated STEM facilitation anxiety, has a limited effect on improving pre-service teacher self-efficacy, confidence in, and competency regarding leading integrated STEM learning activities targeted towards engaging learners in science exploration. However, participant comments on 3D modeling software usability, application within K-12 science learning environments, and perceived K-6 classroom strengths provide important commentary on likelihood of STEM resources such as Tinkercad being adopted into future classrooms.

Keywords: *Integrated STEM, Science education, 3D Modeling, Anxiety, Cross-Curricular Learning*

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Science education has traditionally been geared towards students exploring the world through inquiry-based learning. Much of how K-12 educators view science education harkens back to Dewey's notion of science needing to transition from "an accumulation of ready-made material [to] a method of thinking, an attitude of mind" (Dewey, 1910, p. 122). Today, this conception of thinking scientifically has been reimagined as engaging learners in "scientific inquiry situated in the context of technological problem solving" (Sanders, 2008, p. 21) within science, technology, engineering, and math (i.e., STEM education).

The most applied form of STEM education within science contexts involves facilitating knowledge transfer between SM (science and math) and TE (technology and engineering) (Xie et al., 2015) and implies the two subjects are brought together as a whole (i.e., integrated) (Council et al., 2014). Thus, integrated STEM is described as creating a learning environment where the major focus is on "building, modifying, and/or repurposing material objects, for playful or useful ends, oriented towards making a 'product' of some sort that can be used, interacted with, or demonstrated" (Martin, 2015, p. 31). Integrated STEM has also been defined as "an educative inquiry-based practice…that emphasizes creative, improvisational problem solving" (Bevan et al., 2015, p. 98) and as "the creative production of artifacts in their…physical and digital forms to share…with others" (Trust et al., 2018, p. 20). The common theme between these three conceptions of integrated STEM (and others like them) is the design, build, test framework of the engineering design process.

STEM education has become inundated by experts, politicians, and education stakeholders expressing opinions about how best to incorporate technology, engineering, and math into science learning within K-12 classrooms. Advocates for the status quo of each STEM discipline being taught as stand-alone content view "STEM education" as rebranding of traditional classroom practices to garner support for career fields of the future (Breiner et al., 2012). Others view STEM education as the natural blending of two or more of the STEM subjects during authentic, real-world, learning experiences (Kelley & Knowles, 2016). Irrespective of which side of the debate one stands, newly licensed K-6 educators enter their first classrooms with depressed confidence and heightened anxiety for leading science, engineering, and technology activities compared to other subjects (Novak & Wisdom, 2018; Raulston & Alexiou-Ray, 2018) primarily due to minimal understanding of pedagogical and methodological best practices (Dare et al., 2018; Douglass & Verma, 2022; Holincheck & Galanti, 2022).

Increased pressure on elementary educators to integrate science, engineering, and technology into K-6 classroom content has been a constant source of in-service teacher anxiety and reduced self-efficacy in elementary classrooms (Domingo & Garganté, 2016; Shernoff et al., 2017). Moreover, research involving grade 7 through 12 science teachers found that confidence in teaching engineering and technology is inextricably connected to familiarity with the tools and techniques applied in the engineering design process (Han et al., 2023; Smith et al., 2021)

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especially surrounding 3-dimensional (3D) printing. Less research has been done to determine the relationship between pre-service elementary teachers' familiarity with specific engineering/technology tools such as Tinkercad (a 3D modeling software), including STEM teaching techniques for its use, and pre-service teacher concerns for future classroom application. The time-tested notion that K-12 educators teach in much the same way as they were taught (Ausubel, 1963) still dominates the educational research landscape as evidenced by Sandall et al. (2018), Shernoff et al. (2018), Dare (2018), and Han (2023) to name a few. Furthermore, the relative novelty of STEM education within K-12 the setting means current pre-service teacher undergraduates have little to no classroom experience to draw from. The reliance on past teacher examples results in novice teachers turning to worksheets, textbooks, and static models to supplement drill and practice activities and a hesitancy for venturing into the unfamiliar territory of Tinkercad modeling and 3D printing (Raulston & Alexiou-Ray, 2018; Sprague et al., 2022).

When scientific concepts, systems, and phenomenon are eventually "explored" in the classroom, teachers rely on cookbook confirmatory "lab" activities/experiments. One example of this confirmatory modeling approach to learning science is a drill and practice learning strategy which asks students to draw "inherited" genetic traits of a fictitious organism (e.g., Reebops). These 2-dimensional (2D) images are then used to explain inheritance patterns of unique features (i.e., number of humps, color of nose, and/or presence of proboscis). Students then share their organism images with the class, pointing out how their model satisfies a set of learned principles of inheritance.

Purpose of the Study

The aim of this study is two-fold. First, to determine the relationship between pre-service elementary teacher familiarity with Tinkercad modeling software and science focused STEM self-efficacy and anxiety. Second, to evaluate pre-service K-6 teachers' pre and post activity anxiety levels related to teaching two related STEM domains simultaneously: (a) science – patterns of heredity and (b) technology – digital modeling. With the advancement of digital imaging technology, many classroom teachers are being pressured to incorporate some form of digital imaging practice within their classrooms (Sprague et al., 2022). When anticipating the adoption of STEM learning activities in K-6 classrooms teachers face decisions about how to integrate the TE aspects into science and math topics (Clements & Sarama, 2023). The following research questions were identified to guide collection of quantitative and qualitative data to explain the impact prior 3D modeling experience has on pre-service teacher perceptions of teaching STEM lessons.

1. Do Tinkercad organismal phenotype modeling experiences reduce anxiety for facilitating science activities involving 3D modeling technology?

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2. What impact does combining Tinkercad modeling software with organism phenotype representation have on the interplay between anxiety, self-efficacy, and perceived competency with K-6 technology and engineering design standards?

Review of Existing Literature

Today's elementary educators are expected to distill large amounts of content knowledge into measurable learning activities that capture short attention span students' interest long enough for them to initiate construction of usable knowledge (Stewart, 2021). This can be challenging for any K-6 teacher, more so when the pressure to incorporate STEM learning experiences and unfamiliar technology is placed on novice teachers. These challenges are predominantly attributed to inexperience with STEM activities and limited interaction with complex and costly technology (Clements & Sarama, 2023; Lawrence & Tar, 2018; Rapanta et al., 2021). These restrictions have had the unfortunate consequence of teachers placing greater emphasis on training students in technology use for information access rather than on technology as a tool to collect, report, and display information in cohesive units of knowledge (Reich, 2019; Strimel et al., 2016).

Knowledge and expertise

Research has consistently shown that depth of knowledge is more applicable during cross-curricular (i.e., integrating two or more subjects) learning activities than breadth of knowledge because mental supports are grounded by alternative understandings of content (Brown, 1975; Moreno-Bote et al., 2020; Turner et al., 2002). Moreover, new knowledge is linked to existing knowledge through retrieval practice links that facilitate knowledge transfer to other contexts (Karpicke, 2017). While the difference between in-service and pre-service teachers may be a teaching contract, the difference between an expert teacher and a novice is based on access to grounded pedagogical and methodological mental supports on which to attach new teaching knowledge. Macleod and Bodner (2017) point out that when comparing experts to novices, being an expert does not necessitate having a better recall of learned content (i.e., memory), just better ways for encoding, organizing, and retrieving knowledge that facilitates the finding of patterns and meaning more quickly and efficiently.

Transition from teaching science as a stand-alone (siloed) subject to an integrated STEM approach requires increased expertise on the part of the teacher. When teachers have a deep store of subject matter content knowledge and classroom experience from which to draw, they will find it easier to facilitate integrating topics from STEM subjects they are less confident with. Moreover, increased effort is being made to assist in-service teachers to transition current siloed classroom practices to integrated approaches (Dare et al., 2018; Sandall et al., 2018; Stubbs &

Myers, 2016) and for pre-service teachers to develop entry level mastery of integrated STEM pedagogy (Hallström & Schönborn, 2019; Sandall et al., 2018; Wang et al., 2011).

One teaching strategy that relies on teacher expertise for success is the use of content specific conceptual and mental models (Ornek, 2008). These experiences are said to afford future classroom teachers' opportunities to work with a variety of STEM relevant models through an integrated approach. Experience with mathematical, computer, and physical models is said to improve subject-matter self-confidence by contributing to depth of knowledge development necessary for increased teacher self-efficacy (Hunt, 2013; Justo López et al., 2019; Ornek, 2008). K-6 pre-service teacher perceptions of their ability to relate concepts and ideas to specific contexts and organize information in a way that will facilitate students' retrieval and application is a major contributor to anxiety for facilitating integrated STEM lessons (Novak & Wisdom, 2018). Research by Novak and Wisdom (2018) identifies anxiety in-service and pre-service elementary teachers feel towards facilitating STEM education is due to inexperience with associated engineering processes such as rapid prototyping, 3D printing, and associated technology.

Modeling within STEM education

Literacy across multiple subjects remains a key aspect of pre-service elementary teacher knowledge acquisition within undergraduate education programs as students learn to transform knowledge into action and then effectively communicate that knowledge orally, visually, and/or in written formats (Raulston & Alexiou-Ray, 2018). One way instructors in undergraduate programs can provide pre-service teachers opportunities to demonstrate cross-subject competency is by challenging pre-service teachers to engage with digital models and modeling as students and as future teachers. Engaging with digital models from diverse subject areas as well as learning core pedagogy/methodology applications closely aligned with content specific phenomena, processes, and/or theories will aid future classroom integration practices (Schmidt & Huang, 2021). Concentrated engagement with subject specific digital models enables pre-service teachers to quickly connect theory with practice as they discover for themselves, affording them greater understanding of their own learning (Council et al., 2000). Moreover, working through theory and application "stuck points" during their own discovery process gives them the tools to support their future students' learning; often hampered by preexisting misconceptions, skill deficits, and decreased aptitude (Hunt, 2013; McDaniel & Einstein, 2005).

If K-6 pre-service educators are to develop self-confidence in facilitating engineering design curriculum they must engage in learning activities requiring them to design, build, and modify objects in creative, improvisational ways. Introducing an integrated STEM approach to learning activities within undergraduate pre-service teacher preparation programs is one promising way of affording future teachers the opportunity to communicate lesson objectives, concepts, and expectations using age-appropriate language and activities (Dare et al., 2018;

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Ejiwale, 2013; Kelley & Knowles, 2016). In this way K-6 pre-service teachers become adept at student-centered inquiry-based science knowledge acquisition by simultaneously integrating technology, engineering, and/or math teaching methodologies, practices, and pedagogy into the creation of learning experiences that engage students with models and the modeling process (English, 2016).

Theoretical and Conceptual Framework

Integrated STEM learning activities that combine science, technology, and engineering are grounded in the principle that infusing the engineering design processes with scientific methodology results in physical models that can be iteratively refined during the investigative process (Bevan, 2017; Godhe et al., 2019; Martin, 2015). This has precipitated from numerous researchers who recognized that effective STEM instruction is not simply a matter of combining learning objectives from different subject matter courses, rather there needs to be thoughtful input into how best to organize learning so that it is authentic and coherent (Justo López et al., 2019; Kay & Knaack, 2007; Merrill, 2002; Ornek, 2008; Sims, 2006). Unfortunately, implementation of such applications as digital modeling has been hampered by traditional expectations related to content standardization and ill-defined STEM specific learning outcomes (Ashton, 2014; Holincheck & Galanti, 2023; Samara & Kotsis, 2023).

One contributing factor is a lack of understanding related to what integrated STEM education entails (Breiner et al., 2012; Sanders, 2008; Shernoff et al., 2017). Research continues to point out that most undergraduate K-6 pre-service educator programs view STEM in a manner that "reinforces a disconnection between the different STEM disciplines" (Struyf et al., 2019, p. 1388). Furthermore, Hallström and Schönborn (2019) indicate that teachers struggle with designing classroom activities where two or more of the STEM subjects (outside the SM and TE conceptualizations) are integrated in both meaningful and relevant ways.

Elementary education majors identify intrinsic attributes such as working with children, making social contributions, shaping the future of children, and prior teaching experiences as motivating factors for becoming K-6 teachers (Bilim, 2014) while STEM content-specific teachers maintain a considerably different self-identity (Avraamidou, 2014). One articulated reason for the difference between K-6 teacher and STEM discipline teacher identity is elementary teachers' commonly held feelings of uneasiness, worry, and/or nervousness towards teaching science and by extension STEM lessons (Novak et al., 2022; Novak & Wisdom, 2018).

Widely accepted research findings have established a connection between teacher anxiety and interest in science education (Deci et al., 1994; Deci & Ryan, 1985), competence towards science, technology, and engineering standards (Novak et al., 2022; Novak & Wisdom, 2018), and teaching self-efficacy (Enochs & Riggs, 1990). As educational technology has evolved from blackboards and chalk to interactive digital animations, K-12 educators have found themselves

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forced to constantly adapt to newer ways of providing learning opportunities for their students. Over time learners have become more adept at interacting with technology in a variety of ways and in multiple settings (Afzal et al., 2023) partially due to evolving teachers' perceptions of technology's usefulness in achieving learning objectives.

Adapting pedagogy and methodology in response to each newly identified educational technology can contribute to already existing subject matter anxieties. If K-6 educators are to move beyond merely dabbling in educative technology to explore it's use in facilitating learning they must have opportunities to individualize the technology and explore ways of integrating it into best practice (Domingo & Garganté, 2016; Lawrence & Tar, 2018; Rapanta et al., 2021). While in-service K-6 teacher's evolution of instructional practice and technology integration is grounded in professional development opportunities backed by extensive classroom expertise, pre-service elementary teachers require purposeful guidance as they assimilate new ways of thinking and "doing", especially as it relates to developing STEM activities that integrate educational material from multiple domains (Raulston & Alexiou-Ray, 2018; Reich, 2019; Tondeur et al., 2012).

When it comes to technology use in the classroom, one common approach to mastery development involves modifying existing skill with an inherent reward following a period of struggle as successive ability levels are achieved (Ahmad et al., 2020). The progressive development through periodic struggle is grounded in constructivist theory of going from not knowing how to do something to being progressively adept or skilled as learners practice with concepts, and experience different instructional strategies (Ertmer & Newby, 2013). Moreover, it is important to recognize content knowledge mastery is predominantly modeled by a teacher's existing ability and skill level, which prior research has directly tied to feelings of anxiety, self-efficacy, and competence (Deci et al., 1994; Deci & Ryan, 1985; Enochs & Riggs, 1990; Novak et al., 2022; Westerback, 1984). Thus, prior experience with digital modeling technology should afford teachers a foundation on which to assist learners through challenges, roadblocks, and limitations with sincere positive affirmations. Moreover, learners' gain content mastery and develop internal reward mechanisms that in turn contribute to teacher competence (Mojavezi & Tamiz, 2012).

Huitt and Hummel (2003) state that as teachers model assimilation of learning strategies from one scenario to another they are scaffolding knowledge construction desired from learners. It is through the modification of preexisting learning strategies that teachers will successfully incorporate integrated STEM challenges using discovery-/inquiry-based learning activities. The advantage of K-6 educators developing technology skills while simultaneously learning STEM content is an increased confidence in their ability to assist learners constructing course specific content knowledge and/or skills from a shared entry point (Caprara et al., 2006).

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The complex interconnected relationship between anxiety, self-confidence, self-efficacy, and expertise is exemplified in Figure 1. Changes to any one of these characteristics has corresponding effect on the other three (e.g., increases in expertise leads to increased self-confidence and self-efficacy while at the same time decreasing in anxiety).

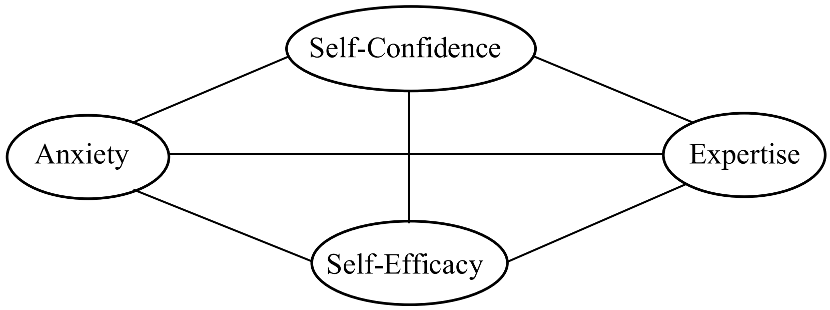

Figure 1. Interconnected Nature of Anxiety, Self-confidence, Self-efficacy, and Expertise

A teacher's belief in their capacity to facilitate the finding of patterns and meaning is one factor contributing to self-efficacy in producing expected student performance (Caprara et al., 2006). Teacher self-efficacy and self-confidence have a complementary relationship as trust in one's ability to produce expected student performance has a positive effect on one's capacity to facilitate the expected student performance (Ball et al., 2017; Mojavezi & Tamiz, 2012; Thorndike, 1927). If we define teaching expertise using a continuum of increased ability to encode, organize, and retrieve their memories of successfully facilitating student performance then improved ability for finding patterns and meaning from learning activities will lead to increased self-efficacy and self-confidence. On the other hand, increased levels of anxiety tend to lower self-confidence and self-efficacy which in turn hinders development of expertise (Novak et al., 2022).

Methodology and Research Design

A convergent parallel mixed methods approach (see Figure 2) was taken to explain the impact Tinkercad modeling software use in a pre-service teacher life science course has on anxiety, confidence, self-efficacy, and interest in teaching STEM in future K-6 classrooms. Quantitative and qualitative data related to intrinsic motivation, anxiety, efficacy beliefs, and STEM standards competence were collected and analyzed. Numerical data in the form of pre- and post-surveys bookended recording of small group observation field notes and informal interviews. Observation notes were recorded while participants discussed the modeling process in peer groups during the use of Tinkercad modeling software. Statistical analysis of quantitative data and themes discovered from qualitative data were later organized around student statements while using modeling software to create 3D representations of constructed marshmallow "organism" models. Comparisons were then made between quantitative and qualitative data to identify patterns in conversations, experiences, and expressions across multiple lab groups and laboratory sections.

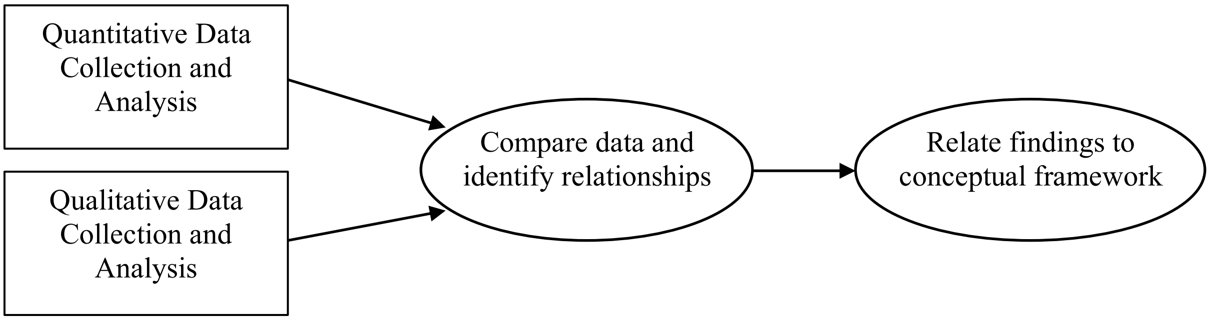

Figure 2. Experimental Design Flowchart

Once all qualitative and quantitative data was collected, analyzed and compared, conclusions were drawn from the data to illuminate the impact of Tinkercad modeling software expertise on the interplay between STEM activity facilitation anxiety, self-efficacy, and perceived competency with K-6 technology and engineering standards. Student conversations while interacting with modeling software and informal interviews were further analyzed to explore impact of organism modeling on reducing STEM technology literacy anxiety and promoting understanding of foundational genetics principles.

Participants and Context

Participants of this study are undergraduate pre-service elementary teachers enrolled in a biology for non-bio majors. The fact that they will one day be expected to teach K-6 grade students a wide variety of subject makes them ideal for exploring anxiety for teaching, competence, self-efficacy, and confidence. The non-biology major course specifically connects learning activities with teaching methodology. Moreover, course activities that focus on illustrating organismal phenotype (i.e., observable characteristics of an organism) can easily be restructured into a 3D modeling project assignment and incorporated across multiple sections of the course (N=128 in the spring of 2023).

Students in this course are either in their freshman (2nd semester) or sophomore year (4th semester) of the Elementary Education Program (Pre-K through Grade 6) at a large mid-western R1 university in the USA. Because participants are early in their undergraduate program, they are less likely to have extensive classroom experience to draw from and more likely to express anxiety for the unknown and lack of confidence in their teaching ability. Moreover, most participants are female (n=124) and in their freshman year (n=115). Thus, all data was grouped together as a single population rather than identifying subgroups.

The Biology for Elementary Teachers course (BIOL20600) was developed around two primary goals of the course: 1) preparing preservice elementary teachers with biology content

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knowledge necessary for teacher-licensure and 2) exposure to life science learning activities directly transferable to future elementary classrooms. Moreover, students in the course are introduced to appropriate pedagogy, technology, and reflective practices aligned with age-appropriate science content knowledge for conducting scientific inquiry with K-6 learners. Additionally, participants work collaboratively throughout the semester in learning communities of three or four students to complete laboratory-based activities and are encouraged to continue collaboration outside of class. These collaborative activities take the form of proofreading one another's assignments, engaging in asynchronous discussions, and providing constructive peer feedback.

Procedures and Materials

Each of the BIOL20600 lab sections completed a lab activity where they created "Reebops" from genetics determined by a coin flip and using marshmallows, toothpicks, push pins, small nails, and pipe cleaners (see Figure 3a and 3b). Next, they were assigned the task of creating 3D images of their "Reebop" model using Tinkercad software. A 5E Learning Cycle for inquiry-based science teaching is employed throughout the semester as a model for science instruction. During the Engagement Phase of the Reebop genetics module, students completed pre-activity surveys prior to engaging with Tinkercad modeling software through a tutorial on how to manipulate objects in the design work-plane. During the Exploration Phase, each student "played" with Tinkercad modeling features as they created their 3D model of their corresponding physical Reebop marshmallow model. During the Evaluation Phase students presented their designed Reebop phenotype 3D models and related how their model exemplified key phenotypic features of their physical models. The Evaluation Phase was followed by students completing post-activity surveys.

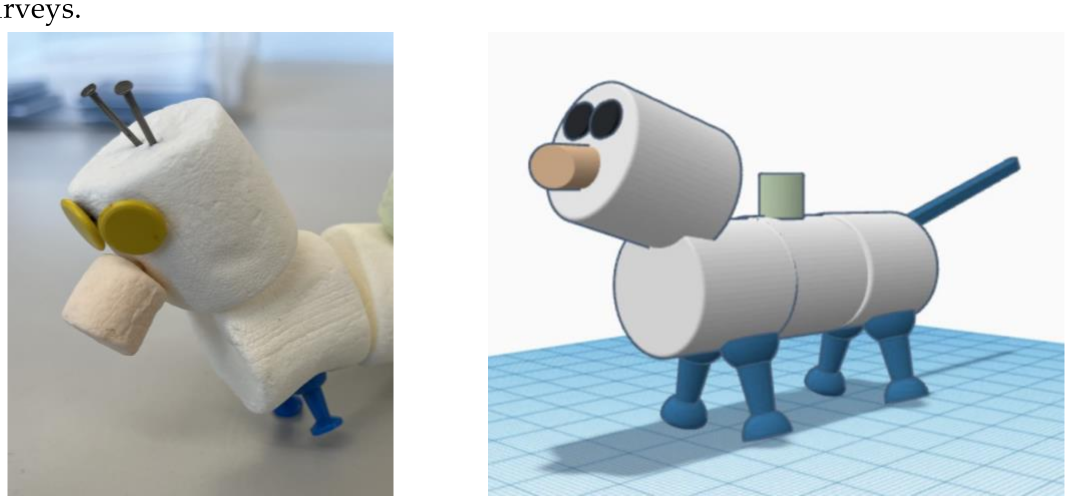

Image a) Physical model   Image b) 3D digital model

Figure 3. Physical and Digital Reebop Models

Data Sources

All students were encouraged to complete the Interest in Science questionnaire adapted from the interest/enjoyment subscale of the Intrinsic Motivation Inventory (Deci et al., 1994; Deci & Ryan, 1985) to assess undergraduate student interest in learning science and doing science projects (see Appendix A). The interest in science sub-scale includes five Likert-type items with an interest in science score being calculated by averaging the five items of the scale. Cronbach's alpha test of internal consistency and reliability is reported as α=.86 (pre) and α=.79 (post) (Novak & Wisdom, 2018).

Teaching anxiety was measured using the Science Teaching Anxiety Scale (STAS) developed to assess pre-service elementary educator anxiety towards teaching science and science projects (Novak et al., 2022; Novak & Wisdom, 2018) (see Appendix B). Modifications were made to the original mathematics anxiety scale (MAS) questionnaire changing items such as "Math does not scare me at all" and "I seldom panic during a math test" to "Teaching science does not scare me at all" and "I seldom panic while teaching a science lesson." This scale allowed for the effective shift of anxiety assessment from math to science with negligible impact on validity of the instrument with an internal consistency and reliability of α=.85 (pre) and α=.87 (post) (Novak & Wisdom, 2018).

Elementary science preservice teachers' self-efficacy and outcome expectancy was assessed using the Elementary Science Teaching Efficacy Belief Instrument (STEBI-B) developed to measure elementary pre-service teachers' constructs of self-efficacy (Enochs & Riggs, 1990) (see Appendix C). Averages of the self-efficacy and outcome expectancy scores were obtained with self-efficacy Cronbach's α=.79 (pre) and α=.89 (post) while outcome expectancy Cronbach's α=.70 (pre) and α=.41 (post) (Novak & Wisdom, 2018).

Competence in technological and engineering design science standards were evaluated using the three Novak and Wisdom (2018) developed five-point Likert-type questions asking preservice teachers how confident they were that they could teach the competencies, identify problems and potential technological/engineering solutions, and understand the design process and role of troubleshooting (see Appendix D). These questions are in line with Next Generation Science Standards (NGSS) with which course content is aligned. The technology and engineering standards exhibit a Cronbach's α=.89 (pre) and α=.86 (post) (Novak & Wisdom, 2018)

Throughout the modeling process, lab section teaching assistants (TAs) and course instructor recorded student communication field notes for each table group. TAs were provided training on recording field notes prior to Tinkercad modeling activity. Once the Tinkercad modeling activity was over, BIOL20600 students then self-identified as being willing to participate in an informal interview session to explore their experience with Tinkercad modeling. During these interview sessions, students were asked about their experience using Tinkercad modeling software, their confidence in teaching integrated STEM activities, and their likelihood of repeating Tinkercad modeling activities in their future classrooms. The decision for informal interviews sessions was based on the number of participating students (n=25) and limitations for scheduling interview time blocks close to the end of the semester and compatible with participants and interviewee schedules. The decision to limit the number of students interviewed to 25 was done because only one of the researchers was available to conduct the interview.

Data Analysis

All quantitative data was collected and analyzed using pre-determined scoring procedures associated with each instrument (see appendix for details on scoring): Student pre- and post-test interest in science, perceived competence in K-6 Science and Engineering Practices standards, anxiety toward teaching science, and science content knowledge. Once all survey instruments were scored, SPSS software was used to run statistical analysis of scored responses. Table conversations fieldnotes and interview responses were deductively analyzed to identify 1) key procedural modeling aspects, 2) modeling concerns, 3) questions posed by students, and 4) indications of design thinking. After one table group's field notes were analyzed using the four pre-determined parameters, discrepancies were discussed and rectified prior to coding of remaining table group fieldnotes. Table group codes were then compared across table groups to identify patterns of behavior and development of expertise. This two-step process provided researchers a better understanding of student learning experiences and attitudes toward 3D modeling projects beyond the survey data. Finally, a constant comparative analysis was used to determine emerging patterns and themes from informal interviews, lab table discussion fieldnotes, and survey data. The data was identified as independent elements and similarities and differences across the three data sets were illuminated and explored.

Validity, Reliability, and Trustworthiness

Because the surveys targeted specific aspects of pre-service teacher perceptions, deductive coding of table-talk conversations and informal interview sessions was implemented rather than inductive coding. Once the coding process was complete, qualitative and quantitative data sets were analyzed for details relevant to motivation, anxiety, self-efficacy, and self-confidence. Neutrality of findings was maintained by section TAs and course staff collecting raw data as part of the course lesson improvement process. This was also instrumental in minimizing researcher bias during content mining of conversations and informal interviews. Initial conversational questions TAs asked participants during Tinkercad modeling fieldnote collection were as follows:

- What challenges did you experience and how did you address those challenges?
- What could be done to better to support student learning?
- How could the learning activity be improved?

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Furthermore, researcher bias for any particular response was further minimized by placing the discussion and subsequent coding of feedback considering improving existing learning experiences.

Results

It was assumed there would be differences between pre-/post-activity responses on each survey instrument (e.g., science teaching anxiety, outcome expectancy, teaching efficacy, standards confidence). This was confirmed by table talk during the modeling process and the evaluation phase of the learning activity. Student comments initially involved complaining about not knowing how to use Tinkercad software. However, as students persisted, and learned how to manipulate the available Tinkercad building blocks their conversations turned to

"Wow, how did you do that?"
"I can't figure out how to add the toothpicks."
"Where do you find the toothpicks?"
"They are in the household objects section, let me show you."

Perceived differences between pre- and post-survey data resulted in z-scores being computed for each post-activity item to determine significance ($H_o = M_{pretest}$).

Table 1.
Means and Standard Deviations of Indicators Measuring Anxiety Toward Teaching Science.

Item	**Pretest (N = 94)**		**Post-test (N = 74)**	
	M**	**SD**	**M****	**SD**
Teaching science does not scare me at all.*	3.35	1.104	3.12	1.110
It would not bother me at all to teach topics in elementary Earth and Space Science.*	3.01	1.187	2.89	1.165
It would not bother me at all to teach topics in elementary Life Science.*	2.73	1.049	2.72	1.117
It would not bother me at all to teach topics in elementary Physical Science.*	2.98	1.067	2.86	1.151
It would not bother me at all to teach topics in elementary Technological and Engineering Design.*	3.85	1.164	3.42	1.182
I seldom panic while teaching a science lesson.*	3.34	1.063	3.14	1.114
I am usually at ease while teaching a science lesson.*	3.23	1.159	3.01	1.129
I am usually at ease interpreting and communicating science concepts.*	3.18	1.047	2.95	1.081
Teaching science makes me feel uncomfortable, restless, irritable and impatient.	2.12	1.046	2.18	1.052
Teaching science usually makes me feel uncomfortable and nervous.	2.32	1.090	2.31	1.084
I get a sinking feeling when I think of teaching a difficult science concept.	2.51	1.268	2.36	1.067

My mind goes blank, and I am unable to think clearly when planning a science lesson.	2.20	1.053	2.14	1.102
Preparing students for a science test would scare me.	2.19	1.050	2.11	0.930
Walking into a school and thinking about teaching a science lesson makes me feel uneasy and nervous.	2.16	1.081	2.15	1.043

*Indicates items that were reverse scored
**Lower values indicate lower anxiety, and higher values indicate higher anxiety levels about teaching science; possible score range 1-5

While post-activity responses measuring anxiety toward teaching science (Table 1) varied from the pre-activity responses, only one item was found to indicate any degree of significance (e.g., items 5). Initial statistical analysis of the Novak and Wisdom (2022) science anxiety teaching scale data indicates normal distribution by the fact each item's mean, median, and mode fall near the center of the distribution and the graphical distribution is essentially symmetrical. The one exception to this is Item 5 pre-test being positively skewed (M=3.85, median=4, mode=5). Additionally, all but one of the post-test means were lower than pretest means indicative of reduced anxiety about teaching science, technology, and engineering design. The largest pre-/post-test score gap came in item 5 (Δ=.43; p=.029) indicating statistical significance in anxiety reduction for teaching topics related to technology and engineering design.

Table 2.
Means and Standard Deviations of Indicators Measuring Outcome Expectancy.

Item	**Pretest (*N* = 84)**		**Post-test (*N* = 66)**	
	M**	**SD**	**M****	**SD**
When a student does better than usual is science, it is often because the teacher exerted a little extra effort.	3.48	0.685	3.61	0.834
When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.	3.98	0.728	3.79	0.808
If students are underachieving in science, it is most likely due to ineffective science teaching.	3.40	0.808	3.19	0.821
The inadequacy of a student's science background can be overcome by good teaching.	3.89	0.640	3.85	0.680
The low science achievement of some students cannot generally be blamed on their teachers.*	2.87	0.818	2.84	0.828
When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.	3.57	0.765	3.75	0.636
Increased effort in science teaching produces little change in some students' science achievement.*	3.00	1.151	2.91	1.026
The teacher is generally responsible for the achievement of students in science.	3.58	0.698	3.63	0.832
Students' achievement in science is directly related to their teacher's effectiveness in science teaching.	3.33	0.869	3.52	0.804

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If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.	3.52	0.768	3.81	0.743

*Indicates items that were reverse scored
**Lower values indicate lower outcome expectancy and higher values indicate higher outcome expectancy levels; possible score range 1-5

Post-activity responses measuring outcome expectancy (Table 2) varied from the pre-activity responses, however, one item was found to indicate any degree of significance (e.g., items 10). Statistical analysis of outcome expectancy data indicated all items were negatively skewed. Moreover, items 1, 6, 8, 9, and 10 showed an increase in outcome expectancy while items 2, 3, 4, and 7 showed a decrease in outcome expectancy, with item 5 showed no change. Furthermore, responders' perception that parental comments related to their child showing more interest in science at school was probably due to the performance of the child's teacher was significant (p=.02) with a pre-/post-survey gap for item 10 of Δ=0.35.

Table 3.
Means and Standard Deviations of Indicators Measuring Teaching Efficacy

Item	Pretest (N = 84)		Post-test (N = 66)	
	M**	SD	M**	SD
I will continually find better ways to teach science.	4.26	0.623	4.25	0.823
Even if I try very hard, I will not teach science as well as I will most subjects.*	3.27	0.936	3.22	1.042
I know the steps necessary to teach science concepts effectively.	3.25	0.834	3.63	0.775
I will not be very effective in monitoring science experiments. *	3.74	0.852	3.54	1.049
I will generally teach science ineffectively. *	3.85	0.843	3.75	1.059
I understand science concepts well enough to be effective in teaching elementary science.	3.67	0.948	3.82	0.815
I will find it difficult to explain to students why science experiments work.*	3.50	0.898	3.31	0.988
I will typically be able to answer students' science questions.	3.64	0.771	3.67	0.805
I wonder if I will have the necessary skills to teach science.*	2.55	0.827	2.67	0.944
Effectiveness in science teaching has little influence on the achievement of students with low motivation.*	3.19	0.950	3.24	1.016
Given a choice, I will not invite the principal to evaluate my science teaching.*	3.44	1.022	3.07	1.159
When a student has difficulty understanding a science concept, I will usually be at a loss as to how to help the student understand it better.	2.42	0.853	2.57	1.048
When teaching science, I will usually welcome student questions.*	1.57	0.664	1.81	0.783

*Indicates items that were reverse scored
**Lower values indicate lower teaching efficacy, and higher values indicate higher teaching efficacy levels; possible score range 1-5

Post-activity responses measuring teaching efficacy (Table 3) varied from the pre-activity responses. Two were found to indicate any degree of significance (e.g., items 3 & 13). Statistical analysis of outcome expectancy data indicated items 1-8, 10, and 11were negatively skewed while items 9, 12, and 13 were positively skewed. Moreover, items 3, 6, 8, 9, 10, 12, and 13 showed an increase in teaching efficacy and items 1, 2, 4, 5, 7, and 11 showed a decrease in teaching efficacy. Furthermore, responders' confidence in teaching science concepts effectively increased significantly (p=<.001) with a pre-/post-survey gap for item 3 of Δ=0.24. Responders also indicated a significant increase in willingness to welcome student questions about science content (p=.01) with a pre-/post-survey gap of Δ=0.38.

Table 4.
Means and Standard Deviations of Elementary Technology and Engineering Design Standards Confidence.

Item	Pretest ($N = 94$)		Post-test ($N = 74$)	
	M**	SD	M**	SD
Teach elementary students how to identify problems and design potential technological/engineering solutions.	2.48	1.114	2.73	1.114
Teach elementary students how to outline the design process of technological/ engineering solutions using science concepts.	2.35	1.095	2.70	1.119
Teach elementary students how to explain the role of troubleshooting in solving a technological/engineering problem	2.28	1.072	2.71	1.144

**Lower values indicate lower confidence, and higher values indicate higher confidence; possible score range 1-5

Post-activity responses measuring confidence toward technology and engineering standards (Table 4) varied from the pre-activity responses, two of the three items were found to indicate significance (e.g., items 2 and 3). After completing the modeling activity, responders indicated an increased confidence in teaching students how to outline the design process using science concepts (p=.023) and how to explain the role of troubleshooting in solving problems (p=.01).

Prior to the modeling activity, 37 responders indicated they would choose to teach science to elementary students: with 24 saying no and 23 unsure (N=84). After the modeling activity, 27 responders indicated they would choose to teach science to elementary students: with 23 saying no and 16 unsure (N=66). Prior to the modeling activity, 60 responders felt the majority of science instruction time should be spent in activity-based learning, with 20 feeling time should be equally distributed between textbook-/activity-based learning (N=84). After the modeling activity, 46 responders felt most of the time in science instruction should be activity-based learning, with 16 indicating time should be equally divided between textbook-/activity-based learning (N=66). Prior to the modeling activity, 44 responders felt their effectiveness as a future elementary teacher was on par with a "typical" elementary science teacher while 36 considered themselves above average (N=84). After the modeling activity, 37 responders indicated they were on par with the average elementary teacher while 27 considering themselves above average (N=66).

Table 5.
Means and Standard Deviations for Pre-/Post-test Data, Pooled t-test, and Significance

Variable	Pooled Pretest		Pooled Post-test		Pooled t-test	Sig
	M	SD	M	SD		
Science interest (5 items)	3.02	0.552	3.09	0.610	-1.592	.187
Anxiety about teaching integrated STEM (14 items)	2.80	0.556	2.67	0.447	3.802	.002
Teaching efficacy (13 items)	3.26	0.710	3.28	0.624	-0.359	.726
Outcome expectancy (10 items)	3.46	0.344	3.49	0.371	-0.590	.570
Standards competency (3 items)	2.37	0.101	2.71	0.015	-6.594	.022

Scores were calculated by averaging the total number of items; possible score range 1-5

Discussion

Taken as a whole, pooled quantitative analysis of pre and post surveys found in Table 5 shows that science interest, efficacy, and outcome expectancy did not experience significant change while anxiety and standards competency did see significant improvement after completing Tinkercad modeling activity. Student engagement during the Tinkercad modeling activity supports the notion that participants had an increased interest in science through their devotion to modeling accurate representations of their Reebop's and persevering through stuck points. This is illustrated in a conversation between one pair of lab partners as they created their Reebop 3D models.

> Kaileigh: Hey, how did you add the legs to your Reebop? I found the push pin object, but how did your tilt it?
> Kelsey: You just click on the pin and then the arrow pointing in two directions.
> Kaileigh: Oh. Thanks. This is pretty easy once you figure out how to do all the manipulations. This would have been easier if they showed us how to do it in the first place.
> Kelsey: I know! It took me forever to figure out how to make all the marshmallows the same size. Stu showed me I could just type in the size by clicking on the little box.
> Kaileigh: Seriously! That's all you had to do? . . . Dang, that makes ensuring the traits are accurate so much easier. Now my [Reebop's] eyes look better.

Most discussions of using Tinkercad modeling within future elementary classrooms involved using it with engineering projects. Terra shared that she could "see how it can be used in creating models of the Reebops, this would probably be too complicated for many elementary students, except for maybe 5th or 6th graders. I want to work with kindergarten or maybe 1st grade so . . . I don't think it would work for my students." Murphey indicated that "once you got the basics of how to manipulate the shapes, change colors, align, and group them it was fun to create different things. I can see this being helpful for engineering, but not sure I would use it for science." Annalee on the other hand was more enthusiastic about using Tinkercad, stating "it was pretty cool to see the Reebop come to life. I sent a screenshot to my parents. This is definitely something I will use in my classroom to let students create similar images to Reebops. I think they would have fun creating the marshmallow object and then doing Tinkercad. I feel more confident [teaching it] now that I have done it for myself."

Research Question 1 Findings

The first research question of "do Tinkercad organismal phenotype modeling experiences reduce anxiety for facilitating science activities involving 3D modeling technology" is supported both quantitatively and qualitatively. Anxiety for using Tinkercad modeling software decreased after completing the Reebop modeling activity (See Tables 1 and 5). However, all students did not have the same experience. Thor indicated that "it was difficult to make an accurate representation of the marshmallow Reebop, everything in the 3D model was uniformed . . . you couldn't squish the objects to make them look like the real marshmallows . . . so I don't know how realistic this is. Tinkercad has limitations . . . I wanted it to look more real." Addison said "I didn't like this activity. I get that it is STEM related but why not just do the marshmallow activity? I think elementary kids will have more fun with [the] hands-on aspect of putting marshmallows together and taking it home."

Transferring idiosyncratic student experiences into classroom practice means teachers must recognize that while some students struggled more than others, each student indicated that using Tinkercad got easier, and some students used the software to create more than one image of their Reebop model. Arabella shared that she "went back to [her] dorm and kept playing around with Tinkercad after lab. [She] created a whole family instead of doing the post lab questions." This suggests that as classroom teachers provide learners with engaging 3D modeling activities, no matter what the underlying context may be, students will demonstrate differing levels of success which can be supported in a variety of ways.

Most students had not used any form of modeling software prior to the activity and shared how it was challenging for them to begin with but got easier over time. Benji, Jacob, and Lucy had each worked with modeling software and the engineering design process previously in their high school robotics clubs. Benji shared that "using Tinkercad is a good starting point for elementary kids because it has a lot of basic shapes that they can just put on the work-plane and begin designing. This makes it easier to teach simple engineering principles." Lucy connected Tinkercad modeling to a previous lab activity involving ecosystem design explaining that "students could take the different animals and place them on the work-plane like they want to arrange them in their aquarium."

Experiences like Benji, Jacob, and Lucy point to the use of 3D modeling as a more creative way than just drawing 2D pictures. The use of Tinkercad software affords learners the ability to see their design in 3 dimensions rather than 2 dimensions." Moreover, Jacob suggested "[teachers] could use Tinkercad to help students learn about shapes because they can change the point of view and see other sides of the object."

Research Question 2 Findings

The research question regarding "what impact does combining Tinkercad modeling software with organism phenotype representation have on the interplay between anxiety, self-efficacy, and perceived competency with K-6 technology and engineering design standards" can be further illustrated in the following situation. Roselyn and Grace had unique experiences with Tinkercad as they only accessed Tinkercad using an iPad while others used laptops or desktop computers to complete the activity. Roselyn found it challenging to complete the activity because "I had a hard time working the controls. Other people could use their mouse pad on their laptops to access things, change the shape, or even rotate it. I had to use my fingers on the screen, and it kept messing everything up. Eventually I just gave up and submitted what I had. It doesn't look like my Reebop at all . . . but I tried." Grace had a similar experience sharing "it was really hard to connect things together and make sure they were lined up correctly. Every time I tried to do something new it would mess up what I just did. It is probably easier if you use a laptop or computer but I only have an iPad so I did the best I could."

Conclusions

Using Tinkercad modeling software without the addition of 3D printing appears to reduce anxiety for facilitating STEM learning activities. However, it also appears that the context of the modeling activity matters when it comes to connecting the use of Tinkercad outside the concept of engineering. There appears to be an inherent bias for connecting 3D modeling software with the engineering design process. It is difficult for students to transfer digital 3D imaging to the science focus used in the context of this study. Many comments pre-service teachers made about using 3D modeling in their future classrooms addressed using Tinkercad along with engineering activities. This begs the question of how could an integrated STEM lesson be created at the K-12 level where the 3D modeling activity bridges the gap between science and engineering such that CAD modeling becomes more closely connected to understanding science or math content rather than a tool for engineering?

Evaluation of participant responses suggests bridging knowledge transfer gaps between science and engineering can be addressed by connecting digital modeling to creation of a

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experimental apparatus rather than an organism. Moreover, the educational impact of digital modeling within science contexts may be better served by applying digital modeling software to visually abstract topics or "inventing" organisms suited for specific habitats, ecosystems, or environments. Utilization of Tinkercad with more creative types of activities such as creating an insect would be more in line with the rapid prototyping aspects of the engineering design process digital 3D imaging software is geared towards.

Pre-service teachers indicated that learning to use Tinkercad was beneficial in developing confidence in their ability to teach future elementary students about engineering and doing STEM lessons with this type of technology. However, there was mixed reactions with how appropriate its use was in their future classrooms. This is probably due to the vastly different age-groups within an elementary school and pre-service teacher preference for teaching specific grade levels—some focusing on upper elementary (4-6) and others on lower elementary (K-3). Application of Tinkercad modeling software (and digital 3D imaging) that directly relates to anticipated future classroom age level might be more instrumental in promoting confidence in its use. Moreover, while marshmallow "Reebops" are age appropriate when working with learners developing an understanding of genetics, application of digital modeling appropriate for elementary students may focus on more simplified structures and objects such as basic shapes and everyday objects students are familiar with.

Using Tinkercad to create 3D images of marshmallow models did contribute to a slight increased interest in teaching science, teaching efficacy, and outcome expectancy. While the numerical increase was not significant, results are in line with those described by Novak and Wisdom's (2018) study combining modeling and 3D printing within an undergraduate pre-service teacher methods course. It appears that use of 3D modeling software, such as Tinkercad, alone is instrumental in significantly reducing anxiety and increasing engineering standards competency but 3D modeling coupled with 3D printing has a larger impact on STEM teaching interest, self-efficacy, and outcome expectancy. Thus, learning experiences that combine digital modeling with 3D printing are better suited for integrating science, technology, and engineering in an integrated STEM context than teaching science as a standalone subject using unfamiliar technology.

Limitations

This study explores only the role of modeling software as one aspect of anxiety towards integrated STEM activity facilitation within K-6 educations settings. As such the findings are not directly transferable to other integrated STEM technologies (i.e., 3D printing and rapid prototyping). While the goal has been to explain the interplay between pre-service elementary teacher STEM activity facilitation anxiety, self-efficacy, and perceived competency and expertise

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in K-6 technology it does not address the preceding or subsequent steps in the engineering design process. Moreover, a more rigorous methodological protocol may result in significantly different results, identifying a different impact on reducing anxiety, increasing self-efficacy, and/or improving competency.

Another limitation within this study is the inexperience of Freshman undergraduates with the field of education. This is especially evident in their naiveté towards classroom expectations. Thus, their responses to survey questions must be analyzed considering this—such that while indicative of their perceptions, they cannot be used as an accurate measure of actual anxiety experienced once in front of the classroom. Each learning experience within undergraduate course work and classroom experience over the course of the pre-service teacher program will contribute to reducing anxiety and this is just one off many experiences they will have before their first contracted workday.

Disclaimers

All participants are guaranteed immunity by using pseudonyms chosen from authors extended family – Kaileigh and Kelsey (daughters); Terra and Annalee (daughters-in-law); Murphey, Addison, Roselyn, Lucy, Arabella, Grace (granddaughters); Thor, Benji, and Jacob (grandsons). Furthermore, with all participants being pooling into a single population, male and female names do not represent gender of participants. This research project was conducted with IRB approval and was not conducted using any research funding sources.

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Appendix A

Science Interest Instrument (Deci et al., 1994)

Please read the following questions and choose the answer that best tells how you really feel.

	Not True	Slightly True	Moderately True	Mostly True	Very True
1. I find science enjoyable	1	2	3	4	5
2. Science is just not interesting to me	1	2	3	4	5
3. I like doing work in my science class	1	2	3	4	5
4. I like learning new things about science	1	2	3	4	5
5. In general, I find working on science projects to be interesting	1	2	3	4	5

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Appendix B

Science Anxiety Teaching Scale (with Engineering Concepts) for Pre-Service Elementary Teachers (Novak et al., 2022)

Directions: This inventory consists of statements about your attitude toward teaching science. There are no correct or incorrect responses. Read each item carefully. Please think about how you feel about each item. Circle the choice that most closely corresponds to how each statement best describes your feelings. Complete your responses for all statements. Thank you for your time.

		Not True	Slightly True	Moderately True	Mostly True	Very True
1	Teaching science does not scare me at all.	1	2	3	4	5
2	It would not bother me at all to teach topics in elementary Earth and Space Science.	1	2	3	4	5
3	It would not bother me at all to teach topics in elementary Life Science.	1	2	3	4	5
4	It would not bother me at all to teach topics in elementary Physical Science.	1	2	3	4	5
5	It would not bother me at all to teach topics in elementary Technological and Engineering Design.	1	2	3	4	5
6	I seldom panic while teaching a science lesson.	1	2	3	4	5
7	I am usually at ease while teaching a science lesson.	1	2	3	4	5
8	I am usually at ease interpreting and communicating science concepts.	1	2	3	4	5
9	Teaching science makes me feel uncomfortable, restless, irritable and impatient.	1	2	3	4	5
10	Teaching science usually makes me feel uncomfortable and nervous.	1	2	3	4	5
11	I get a sinking feeling when I think of teaching a difficult science concept.	1	2	3	4	5
12	My mind goes blank and I am unable to think clearly when planning a science lesson.	1	2	3	4	5
13	Preparing students for a science test would scare me.	1	2	3	4	5
14	Walking into a school and thinking about teaching a science lesson makes me feel uneasy and nervous.	1	2	3	4	5

Scoring items: Items 1-8 should be reverse scored

Appendix C

STEBI Form – (Initial Instrument)

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA= STRONGLY AGREE, A=AGREE, UN=UNCERTAIN, D=DISAGREE, SD=STRONGLY DISAGREE

1.	When a student does better than usual is science, it is often because the teacher exerted a little extra effort	SA A UN D SD
2.	I will continually find better ways to teach science	SA A UN D SD
3.	Even if I try very hard, I will not teach science as well as I will most subjects	SA A UN D SD
4.	When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach	SA A UN D SD
5.	I know the steps necessary to teach science concepts effectively	SA A UN D SD
6.	I will not be very effective in monitoring science experiments	SA A UN D SD
7.	If students are underachieving in science, it is most likely due to ineffective science teaching	SA A UN D SD
8.	I will generally teach science ineffectively	SA A UN D SD
9.	The inadequacy of a student's science background can be overcome by good teaching	SA A UN D SD
10.	The low science achievement of some students cannot generally be blamed on their teachers	SA A UN D SD
11.	When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher	SA A UN D SD
12.	I understand science concepts well enough to be effective in teaching elementary science	SA A UN D SD
13.	Increased effort in science teaching produces little change in some students' science achievement	SA A UN D SD
14.	The teacher is generally responsible for the achievement of students in science	SA A UN D SD
15.	Students' achievement in science is directly related to their teacher's effectiveness in science teaching	SA A UN D SD
16.	If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher	SA A UN D SD
17.	I will find it difficult to explain to students why science experiments work	SA A UN D SD
18.	I will typically be able to answer students' science questions	SA A UN D SD
19.	I wonder if I will have the necessary skills to teach science	SA A UN D SD
20.	Effectiveness in science teaching has little influence on the achievement of students with low motivation	SA A UN D SD
21.	Given a choice, I will not invite the principal to evaluate my science teaching	SA A UN D SD
22.	When a student has difficulty understanding a science concept, I will usually be at a loss as to how to help the student understand it better	SA A UN D SD
23.	When teaching science, I will usually welcome student questions	SA A UN D SD
24.	I do not know what to do to turn students on to science	SA A UN D SD
25.	Even teachers with good science teaching abilities cannot help some kids to learn science	SA A UN D SD

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RESEARCH REPORT

Exploring Evolving Perspectives: Research Trends in Attitudes toward STEAM Education

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Abstract
As the number of scholarly publications on STEAM education grows rapidly, international reviews examining its status and trends are pivotal for advancing the field. This study examines the evolution of attitudes toward STEAM education from 2020 to 2024 through a systematic analysis of research literature. The study reveals a notable increase in contributions from Spain, Taiwan, and Turkey, followed by significant input from the USA, China, and Jordan. In research groups, there is a growing focus on teachers' attitudes, alongside continued interest in K-12 and post-secondary STEAM education, indicating shifting research priorities. As for research topics, findings reveal a predominant focus on K-12 learner experiences, alongside significant attention to teaching practices, and emerging interest in post-secondary STEAM education, indicating a comprehensive approach to addressing educational needs across different levels. This review provides valuable insights into recent trends in attitudes toward STEAM education, providing a comprehensive overview of this evolving field.

Keywords: *Attitudes toward STEAM, Trends, Literature review, STEAM education research*

The trend toward STEAM education swiftly gained prominence in today's schools. STEAM serves an educational method that utilizes Science, Technology, Engineering, the Arts, and Mathematics to stimulate student curiosity, promote discussion, and enhance critical thinking (Tytarenko et al., 2021). This interdisciplinary approach not only fosters creativity but also nurtures essential skills for navigating an increasingly complex world. STEAM integration aims to combine multiple disciplines as way to engage students in topics of interest while teaching critical thinking and core content knowledge for future success in careers (Wieselmann et al., 2020). By intertwining various subjects, STEAM education encourages students to explore connections between seemingly different fields, fostering a holistic understanding of concepts and their real-world applications.

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STEAM education garners significant interest across various educational fields (Kareemet al., 2022). Scholars and educators have responded to this on-going call by sharing their academic contributions through various publishing channels. A basic search on Google using the term "STEAM education research" yielded over 109 million results. The abundance of information highlights the rapidly evolving nature of STEAM education and underscores the extensive volume of research in this field. However, despite the breadth of research, the field still lacks a cohesive understanding of how attitudes toward STEAM vary across different educational levels, regions, and stakeholder groups.

Numerous reviews on STEAM education research offer insights into potential methodologies for locating relevant publications (Brown, 2012; Minichiello et al., 2018; Li et al., 2020). In the review conducted by Wang et al. (2020), the authors analyzed 798 articles from 2000 to 2018 across 36 journals to assess trends in STEM education research. Findings indicate a growing global significance of STEM education, with clearer journal identities emerging over time. Both quantitative and qualitative analyses were employed to understand research topics, methods, and authorship nationalities trends. Even so, these reviews do not reflect developments in recent years, emphasizing the importance of conducting an updated study to examine new advancements in the field.

In contrast to general reviews on STEAM education, other reviews concentrate on specific issues within the realm of STEAM education (Margot & Kettler; 2019; Martynenko et al., 2023; Wu & Rau, 2019; Zhao et al., 2022). For example, Martynenko et al. (2023) focused on attitudes toward STEM education based on 23 empirical journal articles published between 2016 and 2022. Margot and Kettler (2019) concentrated on understanding teachers' values, beliefs, perceived obstacles, and required support regarding STEM education, drawing insights from 25 scholarly articles. While these reviews offer valuable insights into specific populations, such as teachers or K-12 learners, they often overlook cross-contextual and comparative analyses of attitudes across diverse regions and educational levels. This limits their utility in identifying universal trends or region-specific developments in STEAM adoption. This gap highlights the importance of understanding the status of trends in STEAM education. Conducting a systematic literature review to explore these trends is necessary.

Prior reviews have utilized one of two approaches for article selection: (a) initially identifying specific journals and then seeking out articles within those journals, or (b) conducting targeted searches in databases using keywords relevant to their focus. After careful consideration, this research will adopt the latter approach, concentrating on attitudes toward STEAM. By considering the aspects discussed earlier, this study aims to provide a clearer understanding of the evolving perspectives on STEAM education, with a focus on developments from 2020 to 2024. It links these attitudes to broader educational outcomes and practical implications, providing valuable insights for educators, curriculum developers, policymakers, and researchers.

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Research Questions

When examining the research focus, studies that explore participants' attitudes towards STEAM become central to the discussion. Specifically, the following three research questions are of interest for addressing.

1. What countries or regions, as indicated by the locations of the authors, have contributed to journal publications on attitudes towards STEAM education?
2. What research groups have emerged in the field of attitudes towards STEAM education based on journal publications?
3. What are the main topics emerging from research on attitudes towards STEAM education, as reflected in academic journal articles?

Method

This study constitutes a condensed literature review concerning attitudes towards STEAM within electronic databases. The following data collection process was applied to find related publications:

1. Search Strategy: The keywords "Attitudes" and "STEAM education" were used in searches across the electronic databases ERIC and Web of Science (WOS). Considering the focus on analyzing the recent status and trends in STEAM education, the search period was defined as January 2020 to April 2024. This timeframe was chosen to capture contemporary research within the field. At this stage, 147 articles were retrieved.

2. Initial Inclusion and Exclusion Criteria: Articles were included if they provided access to the "full text" and were published in "peer-reviewed journals." These criteria ensured that the selected studies met a high standard of academic rigor and were accessible for detailed review.

3. Article Screening and Selection Process: The titles and abstracts of 69 articles were further examined to assess their relevance. Articles were excluded if they did not explicitly address quantitative research methods or lacked a focus on the development or use of scales to measure attitudes toward STEAM. Based on this closer examination, 29 articles were included for detailed review. This decision was made because only these studies met the specific criterion of focusing on scale development within quantitative research on attitudes toward STEAM.

4. Thematic Analysis Approach: An inductive approach was adopted for the thematic analysis. This method allowed the themes to emerge from the data without being constrained by pre-existing frameworks or hypotheses. During the detailed review, studies were categorized based on recurring themes, such as the specific constructs being measured (e.g., student attitudes, teacher perceptions), the target populations (e.g., elementary students, secondary students, middle school students, high school students, University students or teachers), and research objectives. This inductive process ensured that themes were grounded in the data and reflective of the diversity within the reviewed literature.

Data Analysis

The researcher conducted a thorough examination of each article, employing a qualitative thematic review methodology. All articles were obtained and scrutinized by the researcher. Among these studies, various measuring instruments were employed based on the focus of the investigation. In most investigations, attitudes were determined using a questionnaire. Some utilized attitude measures that had undergone prior validation and reliability testing.

The thematic categories were developed through a systematic analysis of research on attitudes toward STEAM education from 2020 to 2024. The research followed a structured approach to classify studies into key categories based on their primary focus. These categories emerged by closely examining the research groups, the topics addressed in the studies, and the countries represented. Table 1 presents an overview of the articles included in the analysis.

Table 1.
Distribution of research articles by profile of participants, data collection tools and topics

Participants	Article (ID)	Country	Data collection tools	Topic category
Teachers	(1), (8), (11), (15), (17), (22), (24), (29), (31), (32)	Jordan, Korea, Uzbekistan, Spain, Chile	Attitude Scales, Questionnaires, Surveys	K-12 Teaching
Primary School Students	(4), (10), (16), (23), (34), (37)	Turkey, USA, Taiwan, Ireland	STEAM Attitude Scale, Questionnaires, Surveys	K-12 Learning
Middle School Students	(6), (8), (10), (12), (21), (30), (34)	UK, Spain, USA, Turkey, China, Ireland	Attitude Surveys, STEAM Attitude Scale	K-12 Learning
High School Students	(3), (9), (10), (39)	Finland, Turkey, USA, Taiwan	Questionnaires, STEAM Attitude Scale	K-12 Learning
University Students	(2), (5), (13), (20), (27), (33), (37)	Russia, USA, China, Taiwan	Questionnaires, STEAM Attitude Scale	Post-secondary

Results and Discussion

In the following sections, findings are presented in alignment with the studies' objectives and each of the three research questions.

The Aims of Studies

Before delving into the specific focus of this research, it's essential to outline the objectives of studies by other scholars included in this study. In a study conducted by Alfayez (2024), the aim was to investigate the availability of STEAM approach requirements among teachers and their attitudes toward the STEAM approach in public schools. Another study, undertaken by

Anisimova et al. (2022), examined the effectiveness of professional development training in shaping students' attitudes toward utilizing distance learning tools within the STEAM education framework.

The goal of the study by Aydin Gürler & Kaplan (2023) was to examine the relationship between 21st-century skills, such as STEAM attitudes, critical thinking, decision-making and gender influence among primary school students. The study validated an educational model utilizing Augmented Reality (AR) to enhance learning in secondary science subjects within the STEAM framework, emphasizing the importance of addressing students' attitudes and the necessity for teacher training (Delgado-Rodríguez et al., 2023). Donmez (2021) was to explore how out-of-school STEM activities influence female students' STEAM career choices and their STEAM attitudes, emphasizing changes in STEAM career interests and considering cognitive styles. Another study by Haddad et al. (2022) explored primary teachers' attitudes towards STEAM education, finding higher awareness among experienced private sector teachers, and recommends unified reform plans for enhanced STEAM implementation. Helvaci et al. (2022) attempted to examine how incorporating Visual Arts Education in the STEAM approach affects students' attitudes toward STEM disciplines. Huang (2020) was to assess the impact of STEAM education compared to traditional methods on students learning attitude and outcome among college students.

The goal of study by Kim and Na (2022) was to examine how technology teachers' attitudes toward STEAM education are influenced by factors like collaboration, receptivity to educational change, expertise, and instructional effectiveness. Another study (Konkus & Topsakal, 2022) investigated the impact of STEAM-based activities on gifted fifth-grade students, revealing positive effects on STEAM attitudes, cooperative skills, and career preferences. Lee (2021) aimed to assess STEAM education integration, focusing on teachers' attitudes toward STEAM and recommending strategies for government-led reforms. The study (Liu et al., 2024) aimed to examine the relationship between marketing knowledge, data literacy, skill enhancement, and learning attitude among students in the context of STEAM application for hospitality and tourism education.

The purpose of this study (López et al., 2021) was to examine Brazilian and Spanish mathematics teachers' views on gamified activities in STEAM education, revealing positive perceptions but also concerns about training and implementation. Mou's (2023) study sought to investigate university students' attitudes towards STEAM through a 3D design project. This study (Ortega-Ruipérez & Lázaro Alcalde, 2023) explored teachers' attitudes towards STEAM activities across various grade levels and subjects, emphasizing implications for STEAM integration in course design. The purpose of the study (Silva-Hormazábal & Alsina, 2023) was to assess the impact of integrated STEAM education on Chilean teachers' attitude, with the goal of informing the design of future training programs in STEAM. Sinha et al. (2020) was to assesses a mobile 3D printing platform's impact on 227 undergraduate students, revealing increased STEAM awareness and positive attitudes towards STEAM education. The study (Togou et al., 2020) sought to assess the impact of Fab Lab-based learning on K-12 students' attitudes towards STEAM subjects, specifically examining motivation, affective state, and perceptions of Fab Lab-based education. The objective of the study by Wu et al. (2022) was to explore the connection between cognitive load, attitude, and learning intention in STEAM education, highlighting key variables influencing students' attitudes and intentions.

Some studies (Lupión-Cobos et al., 2023; Romero-Ariza et al., 2021) aimed to explore the impact of professional development training on teachers' attitudes, addressing associated challenges and opportunities related to teaching collaboration, curriculum, institutional support, methodology, professional development, and student concerns. In some studies, in which students participated, the effect of the STEAM program (Lu et al., 2022), STEAM-based science activities (Aurava & Meriläinen, 2022; Bosman & Shirey, 2023; Boyle, 2021; Flesch et al., 2021; Liu & Ding, 2022; Özkan, 2022) and STEAM workshops (Ying-Yan et al., 2022) on students' attitudes toward STEAM was investigated.

Top 10 countries/ regions where scholars published journals on attitudes towards STEAM education

When it came to the countries/regions where the data was obtained, Figure 1 showed the number of publications by countries/ regions from 2020 to 2024. Most of the research was conducted in Spain, Taiwan and Turkey, followed by the USA, China, and Jordan. In the remaining nations of Chile, Finland, Ireland, Korea, Russia, UK and Uzbekistan, one data set was gathered for each country.

The study reveals a dynamic global research landscape, with Asia, particularly Taiwan and China, leading in research activity. Authors in some countries in Asia were becoming very active in the field over the past several years. This trend is consistent with findings from the IJ-STEM review (Li et al., 2019). Europe, with Spain at the forefront, also shows significant engagement. Contributions from North America, the Middle East, and emerging regions like Turkey also highlight widespread interest.

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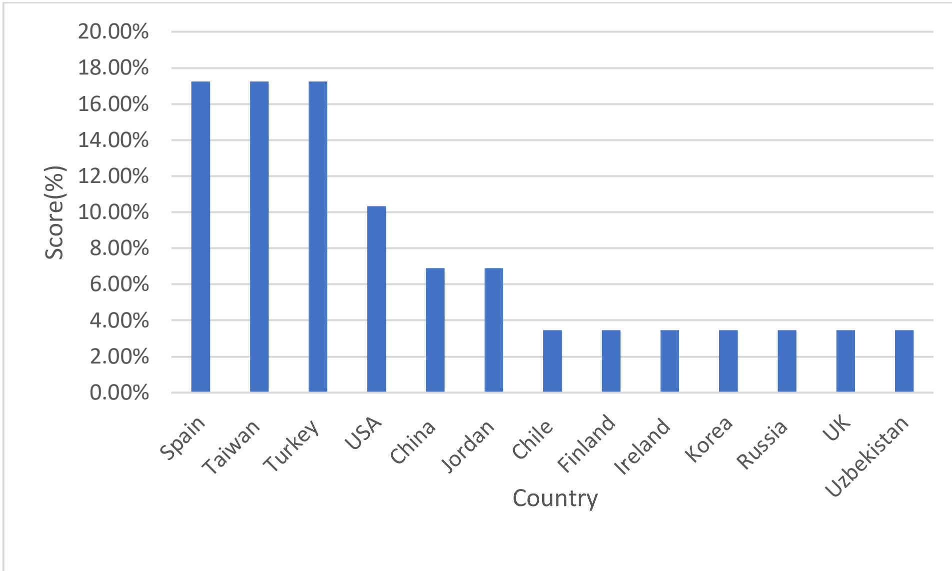

Figure 1. Top 10 authorship countries/ regions (2020-2024)

Published articles by research groups

Upon examination of the research groups, Figure 2 depicted the population distribution within each category. It was observed that studies predominantly featured teachers as the primary group. The research groups were ranked as follows: middle school students and university students constituted the second group, followed by primary school students in third place, and high school students as the last group.

This prioritization of teachers in the research group indicates a strong emphasis on investigating teachers' attitudes toward pedagogical approaches, instructional strategies, and professional development within STEAM education. The ranking of middle school and university students as the second group suggests a secondary focus on understanding learning experiences and outcomes among older students. Primary school students follow, indicating a lesser but still significant emphasis on exploring STEAM education at earlier stages of schooling. Lastly, the recognition of high school students underscores the importance of considering their unique needs and experiences in STEAM education research.

In conclusion, this hierarchical arrangement of research groups indicates a transition from primary student-centered STEAM attitude research to a newfound emphasis on exploring teachers' roles and perspectives. This shift underscores the evolving priorities within the research community, while also recognizing the diverse learning experiences and attitudes of students across various educational stages.

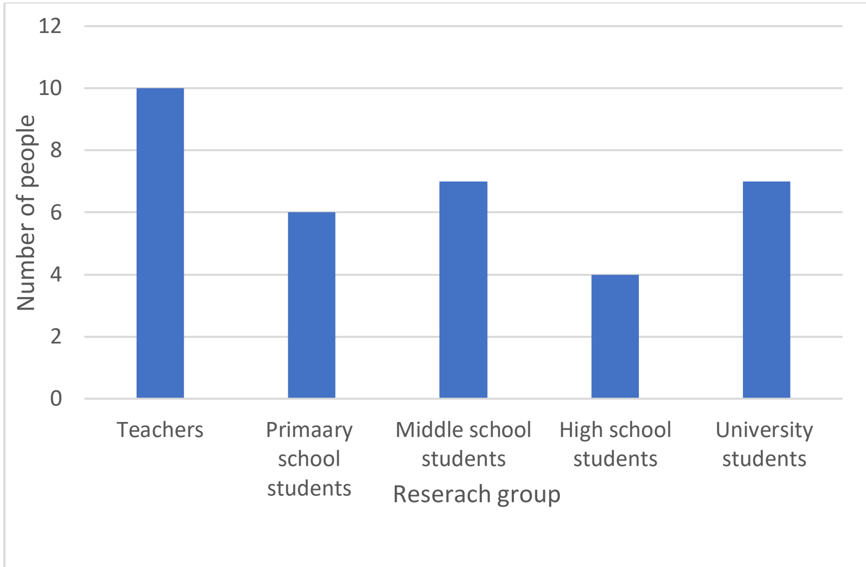

Figure 2. Number of people in different research groups

Published articles by research topics

Figure 3 shows the number of publications in each of the three topic categories. The most frequent category was "K-12 learner, learning, and learning environments," with 13 publications, accounting for 45% of the total. It indicates a strong emphasis on investigating the educational experiences of students in kindergarten through 12th grade across various STEAM disciplines.

The second most researched topic was "K-12 teaching, teachers, and teacher training," comprising 31% of publications, while "post-secondary STEAM education, learners, and learning environments" followed closely behind at 24% of publications. The results suggest that while the research community predominantly centers on K-12 education, there is significant attention given to both teaching and learning aspects within this context.

While "post-secondary STEAM education, learners and learning environments" category receives slightly less attention compared to K-12 education, it still represents a significant portion of the research output, indicating an ongoing interest in understanding and enhancing STEAM education at the post-secondary level. This indicates a notable shift towards addressing STEAM learning in higher education settings. This suggests an acknowledgment of the need to prepare students for STEAM-related careers and lifelong learning beyond the K-12 educational stage, reflecting a comprehensive approach to advancing STEAM education by addressing both learner needs and teaching practices across various educational levels.

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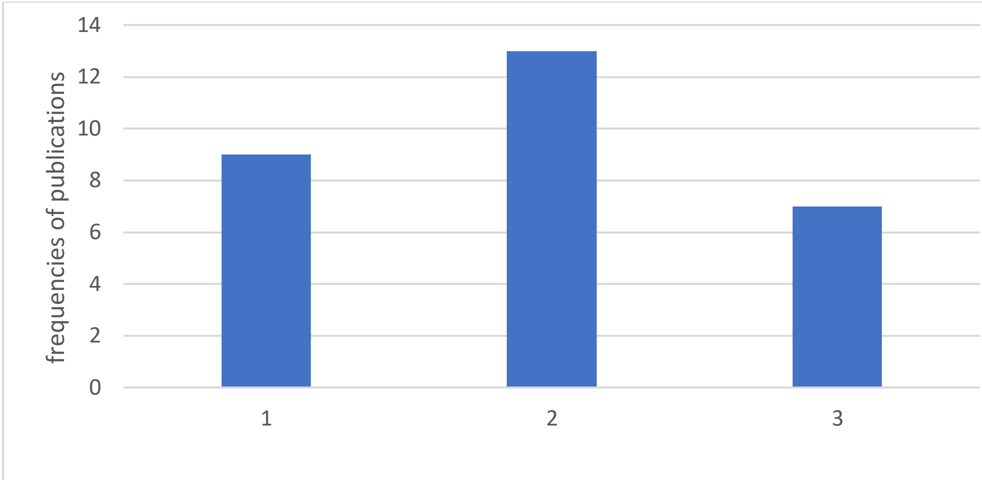

Figure 3. Frequencies of publications' research topic distributions
Note:1=K-12 teaching, teacher and teacher education; 2=K-12 learner, learning, and learning environments; 3=Post-secondary STEAM learner, learning, and learning environments)

Conclusion and Recommendations

Summary of Findings and Significance

In this study, research studies on attitudes toward STEAM between 2020 and 2024 were examined. In contrast to the findings of the previous review (Martynenko et al., 2023), most publications on attitudes toward STEAM were contributed by authors from Spain, Taiwan, and Turkey, with subsequent notable contributions from the USA, China, and Jordan. Authors from various Asian countries have notably increased their activity in this field in recent years, mirroring the findings documented in the IJ-STEM review by Li et al. (2020). This trend underscores the increasing global recognition of STEAM education's importance and reflects a shift towards more diverse, international participation in STEAM scholarship.

Given the rapid evolution of STEAM education globally, researchers often face challenges in gaining a comprehensive understanding of potential leading research groups or topics within the field. This challenge stems from the wide dispersion of STEAM education publications across diverse journals in various fields. The systematic analysis of publications on attitudes toward STEAM education identifies teachers as the predominant research group, with subsequent attention given to middle and university students. This reflects a shift towards understanding the role of teachers in STEAM education, as well as growing interest in how older students engage with STEAM learning. This result may drive a global emphasis on enhancing teacher training and support in STEAM education, as well as targeting the specific needs of older students to better equip them for STEAM careers.

According to the results of the study, the studies in the topic category of "K-12 learner, learning, and learning environments" have been the most prevalent, by far. The analysis also suggests that the research community has a keen interest in both teaching and learning within K-12 STEAM education. This trend is consistent with findings from the IJ-STEM review by Li et al. (2020). The prominence of "post-secondary STEAM education, learners and learning environments" reflects the increasing recognition of extending STEAM learning in higher education settings. This shift could lead to a stronger global focus on early-stage STEAM education, enhancing K-12 curricula and teacher training, while creating smoother pathways to post-secondary STEAM careers and lifelong learning, ultimately preparing a more skilled workforce for future challenges.

Study Limitations

While this study provides an overview of the status and trends of attitudes toward STEAM education research, there are still some limitations. First, the study relied on a specific time frame (2020-2024) for the selection of research publications, which may have excluded important studies published outside this period. Second, the focus was limited to scale development research, excluding other valuable studies that may have contributed to the field. Additionally, the study was restricted to articles indexed in selected databases, which may have overlooked relevant research not captured in these sources.

Future Research Directions and Recommendations

Future research can aim to address these limitations by incorporating a wider range of research sources, including non-indexed studies, and exploring diverse research methodologies beyond scale development. It would also be beneficial to extend the time range for analysis, providing a more comprehensive view of long-term trends in STEAM education. Also, more studies can investigate the evolving roles of teachers and the experiences of students at various educational levels, particularly in non-K-12 contexts.

This study underscores critical implications for educators, curriculum developers, and policymakers in enhancing STEAM education. Given the growing emphasis on post-secondary STEAM education, teachers can prepare students for STEAM-related careers by adopting an interdisciplinary approach that integrates real-world applications to highlight the relevance of STEAM subjects in daily life and future career paths. Curriculum developers are encouraged to design interdisciplinary curriculums, provide professional development for teachers, and integrate global perspectives, particularly from regions with increasing activity in STEAM research, to enhance STEAM education and prepare students for future careers.

Policymakers can prioritize initiatives that advance STEAM education across all levels while promoting global collaboration to facilitate the exchange of best practices and research findings. Such global cooperation can support the dissemination of innovative strategies, enhance equitable access to quality STEAM education, and foster cross-cultural understanding, contributing to the broader advancement of STEAM education worldwide.

Through this exploration, the study sheds light on the studies on attitudes toward STEAM in recent years, offering valuable insights into this evolving field. Work in attitudes towards STEAM education will continue to evolve and it will be interesting to review the trends in another 5 years.

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RESEARCH REPORT

Broadening Perspectives of STEM education: A new Conceptual Framework

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Abstract
This systematic review aimed to uncover the commonalities and divergences in the conceptualisations of STEM education from the literature to develop a framework that depicts how STEM education is framed in various national and global contexts. This study employed a qualitative desktop research methodology to examine the evolution of STEM conceptions over the past decade, focusing on its relevance to the 21st century. It utilised the triangle framing framework to emphasise the three axes of support, that is, the epistemological, psychological, and didactical dimensions. The research was systematically organised into three sequential phases to examine the body of peer-reviewed literature on STEM education. The initial phase involved the identification and retrieval of pertinent studies focused on conceptions of STEM education. This was succeeded by a thematic analysis to develop comprehensive syntheses of the literature. Finally, the synthesised findings were critically analysed to uncover new and nuanced ideas and concepts related to STEM education, pushing the boundaries of current understanding. The themes that emerged from the meta-analysis and synthesis of STEM conceptions were compartmentalised against multidisciplinary and integrated approaches, dominance of disciplines, extending the core disciplines in STEM, policies and practices of STEM education, integrated STEM education, epistemological considerations for STEM education, STEM for employability, and realigning assessment in STEM education. The structured framework, developed from the conceptions that emerged during the meta-analysis and synthesis, is essential for broadening the understanding of STEM education and it opens avenues for future research.

Keywords: *Meta-analysis and synthesis, STEM conceptualisation, STEM education, Triangle framing, framework*

In the ever-evolving landscape of education, the role of STEM has become a subject of extensive debate and research (Yan et al., 2024). STEM-based modalities of instruction, which integrate engineering design, mathematical thinking, scientific inquiry, and technological literacy (Kelly & Knowles, 2016), are crucial to leverage digital advances from the past industrial revolutions (Gleason, 2019) and to prepare a workforce capable of addressing issues and

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challenges related to uncertainty (Penphrase, 2019). The arguments thereof not only point to a need to rethink professional development programmes for STEM teachers and the conventional sciences but also reconceptualise STEM education for 21st century citizens. After all, the compelling arguments concerning STEM education today place it at the heart of the development of 21st century skills and the holy grail - Sustainable Development Goals (e.g., Jakfar et al., 2024). STEM education has become a cornerstone of global political and economic priorities, hence igniting significant discussions and inquiry among pertinent stakeholders who view it as a political tool and economic and educational saviour (Razi & Zhou, 2022). It points to the need to mould the global workforce with academic, technical and soft skills that enable them to fit in the world marked by sophisticated technologies, a globalised economy and social diversity (Kayan-Fadlelmula et al., 2022). It is thus reasonable that such reconceptualisation of STEM education be made sustainable through its national policies that provide coherent frameworks for championing STEM-based strategies and programmes across all education sectors, ranging from pre-primary school to higher education (HE), including research, innovation, employment and industrial development (Marginson et al., 2013). There is a need to develop relevant, clearly articulated and contextualised STEM policies and frameworks based on the community’s conceptions and conceptualisations of STEM education.

Clearly articulated and contextualised STEM education policies and programmes are vital. These are shaped by the global need for STEM professionals who can face economic, societal and environmental challenges in a globalised economy (Spikic et al., 2023). Indeed , in countries with a developed industrial base such as the United States, the priority is on moulding future STEM professionals, hence emphases on pertinent aspects of K-12 STEM education, STEM majors and careers of underrepresented populations, STEM education funding and research, and most importantly “recruitment, retention, recognition, preparation, and professional development of STEM teachers” (Bush, 2019, p. 74; emphases added). In the United Kingdom, STEM conceptualisation is equally based on human capital driven by a commitment to the effectual scientific enterprise and innovation investment system. Like the Gulf Cooperation Council states (Middle East) (see Kayan-Fadlelmula, 2022), China hopes to improve STEM education competitiveness. It has prioritised a formidable, innovative STEM workforce (Yan et al., 2024). Kamsi et al. (2019), drawing from Joseph (2018), argue within the context of FIR-STEM (Foundational Integrated and Responsive STEM), on the importance of human capital equipped with not only skills but also education, knowledge, experience, creativity and motivation. The aspect of human capital is also set out in Science, Technology and Innovation Strategy for Africa, which is enshrined in the African Union Agenda 2063 (African Union, 2012). To achieve technical competences, which are a fundamental requirement of the 4.0 Industrial Revolution (González-Pérez & Ramírez-Montoya, 2022), member states are expected to take a systematic and coordinated approach to human capital development and popularising STEM research and innovation as potential career paths at both secondary and higher education levels including TVETs.

We acknowledge the diversity in conceptions and conceptualisations of STEM education in different national contexts, which include environmental, political, economic, social and technological specificities. We contend that these aspects thereof backdropped our argument that they are key in the development of STEM policies and frameworks. That said, this review is important. It is part of conglomerate projects concerning not only the broadening of the scope of STEM, specifically concerning its global conceptualisation but also critical analysis of how it is currently measured in the world, and situational analysis and the contextual factors that present barriers and opportunities in Mauritius and South African contexts. The researchers' meta-analysis and meta-synthesis approaches, in this case sought to examine existing literature on STEM education. The approaches enabled the researchers to uncover how the conceptions of STEM education have evolved over time, aiming to develop a framework that different educational stakeholders, especially policymakers can utilise in crafting effective STEM Education policies and strategic STEM plans. This is important as it will map out the way forward on how STEM education may be conceptualised at national and global levels in a quest to developing a competent workforce that can enable own institutions to stay competitive in the evolving technology-laden landscape.

The research sought to address the following research questions:

1. What are the commonalities and divergences in the conceptions of STEM education found pertinent in peer-reviewed literature?
2. What are the key themes that emerged from the thematic analysis of the literature on STEM conceptions?
3. What are the new and nuanced concepts about STEM education that emerged from the analysis of the syntheses that were prepared for each identified theme?

Literature Review

This section focuses on an overview of the (i) origins of STEM education, (ii) evolution of the STEM education conceptions, (iii) implementation of the interdisciplinary, integrated, and holistic STEM education, and (iv) STEM education in the North and the South.

Origins of STEM education

The United States government recognized the urgent need to bolster its scientific and technological capabilities in the wake of the Sputnik launch and the space race with the Soviet Union (Vought, 2018). The focus of STEM at that time was on the development of discipline-related specialists in (i) science to engage in intellectual and practical scientific activities to

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systematically study structure, behaviour and phenomena of the physical and natural world, (ii) technology to invent and innovate to improve the world and quality of life, (iii) engineering to control, modify, or design materials, processes, and systems, and (iv) mathematics to use and develop symbolic language for representing reality and making sense of the world with numbers (Bybee, 2011). For Gonzalez and Kuenzi (2012), STEM became the most rapidly growing industry in the U.S. economy as the associated companies continued to ramp up technological innovation to remain competitive across the globe and maintain the dominance of the global North across the world That led to strengthening STEM education, with the ultimate goal of cultivating a robust pipeline of skilled professionals capable of driving innovation and maintaining the country's technological edge. Thus, the conceptualisation of STEM moved from mostly an enactment and interprets orientation to an educational orientation, officially giving rise to STEM education (Feola et al., 2023). The movement around integrating STEM into educational frameworks gained a lot of traction and countries began to recognise that STEM education will help students of all ages develop the 21st century skills they will need to be successful, and to play an effective role, in the future workforce (Payton et al., 2017). This led to the development of STEM-focused curricula in many countries of the world (Barcelona, 2014; Kenedy & Odell, 2023).

Evolution of the STEM education

According to Shirey (2018), education systems have traditionally presented science, technology, engineering, and mathematics as separate disciplines. The focus has been on the improvement of teaching and learning of the sciences, technology, engineering, and mathematics as discrete disciplines to provide the best scientists, doctors, engineers, and ICT specialists to cater for the needs of the economy. However, during the late half of the 20th century, a growing recognition of the limitations of siloed STEM education brought about concerns about workforce readiness and the need for innovation. This fuelled a call for a more integrated STEM approach (Bybee, 2010; Hwang et al., 2024; Lee, 2024). Thus, the interdisciplinary and integrated STEM education emerged to break down the silos between disciplines.

Today’s STEM education advocates for the shift towards an approach to teaching where the traditional barriers erected between the four disciplines are removed (Hwang et al., 2024). It should be noted that, as a first step in the transformation from the siloed to an interdisciplinary approach, the latter explored teaching and learning that bring together two or more STEM subject areas to provide students with a cohesive and practical education that mirrors the interconnected nature of real-world problems and industries (Sanders, 2009). Glancy and Moore (2013) proposed a STEM Translation Model as a framework that makes provision for integrated STEM lessons and activities to encourage students to make translations between the ideas of multiple disciplines. That has since been followed by a gradual movement towards a more synergic approach, termed the integrated STEM (iSTEM) approach where all the different STEM related disciplines work together to create more powerful and impactful learning experiences (Bybee, 2010; Hwang et al., 2024; Lee, 2024). Project-based learning, where students apply their knowledge of science, technology, engineering, and mathematics to solve real-world problems, became a key aspect of this new approach, fostering critical thinking, problem-solving skills, and collaboration (National Academies Press, 2012).

The last decade has witnessed a new paradigm shift in the conception of STEM which goes beyond the approach of integrating the four pillars of STEM to accommodate a holistic approach that opens the integrated STEM whole to other disciplines including non-scientific areas of learning. This encouraged the integration of health, humanities, social sciences, languages development and the arts, giving rise to a host of variations on the acronym from STEM to STEAM (STEM and the Arts), STEMM (STEM and Medicine), STEAMED (STEM, the Arts, Education and Design), and STREAM (STEAM with Robotics or Readings) among others (Belbase, 2022; Ilhan et al., 2019; Kocabas et al., 2020; Lyons, 2018). Curricula developed based on these new conceptualisations of STEM allowed a more holistic development of students. For instance, the addition of Arts to STEM was brought about to improve on the existing knowledge and skills to meet the needs of the 21st century citizens (Belbase et al., 2022). STEAM is gaining a lot of importance globally as creativity and arts form the basis of the 21st century competences such as logical, reasoning, problem solving as well as inquiry skills (Braund & Reiss, 2019; Correia, 2024). The coding and robotics for STEM (C-STEM) program used coding and robotics to help students develop practical problem-solving skills while tackling real-world issues (Wright, 2024).

The opening of integrated STEM education to other disciplines has not only improved development of students' competencies but has also broadened the focus to address societal issues such as the environment, sustainability, and gender equality. For instance, the Community-STEM Project-Based Learning (C-STEM-PBL) approach, where pre-service mathematics and science teachers are involved in project-based learning, incorporates community assets, voices, and needs into their teaching practices. This approach emphasises community involvement, making STEM education more relevant and impactful within local contexts (Nava & Park, 2021). The Environmental STEM (E-STEM) integrates environmental education with STEM disciplines for environment-centred learning, and collaboration among teachers, professionals, and researchers in STEM activity, designed for more authentic learning experiences (He et al., 2024). E-STEM highlights the importance of sustainability and calls for updated curricula and digital infrastructure to address the evolving demands of education (Jasrai & Kaur, 2024). Likewise, Education for Sustainable Development in STEM (ESD-STEM) combines STEM education with the principles of ESD. In addition, gender-specific STEM education (e.g. STEM for Girls and Women) explores the cultural and societal influences that contribute to the gender gap in STEM fields, particularly in specific contexts such as China and Africa. This approach advocates for cultural change, gender-sensitive pedagogy, and research focusing on intersectionality and classroom dynamics to effectively address disparities and increase female participation (Gao, 2024).

Implementation of STEM education

In alignment with the evolving conceptualisations of STEM education, which have transitioned from a compartmentalised, discipline-specific approach to an interdisciplinary, integrated, and holistic framework, the implementation of STEM education varies from one country to the other (Glaze, 2020). In certain countries, the implementation of STEM education is limited to predominantly enhancing individual STEM disciplines (i.e., science, technology, engineering, and mathematics). For instance, South Korea's approach to STEM education is more siloed, with science, technology, engineering, and mathematics taught as separate subjects. However, there are efforts underway to integrate these subjects more effectively. The government has invested in initiatives that promote project-based learning and teacher training in STEM integration (Ryu et al., 2021). Conversely, other countries have adopted a more integrated approach to STEM education, fostering a cohesive and interdisciplinary learning environment (English, 2016). For instance, Singapore and Finland have a strong emphasis on integrated STEM education, where subjects are taught in a way that emphasises their connections in real-world applications. This approach is evident in their national curriculum framework, which encourages the use of project-based learning and encourages teachers to collaborate across disciplines (Brand, 2021).

Though the current position of STEM education varies in different countries, there is an ever-growing movement towards integrated STEM education and curriculum development. To add to this debate, the perspectives on how discipline integration can be achieved remained complex and varied, especially when considering the difference between multidisciplinary, interdisciplinary, and transdisciplinary approaches (English, 2016). While multidisciplinary approach to STEM education includes core concepts and skills being taught separately in each discipline but housed within a common theme, the interdisciplinary approach includes the introduction of closely linked concepts and skills from two or more disciplines with the aim of deepening understanding and skills. The transdisciplinary approach includes the application of knowledge and skills from two or more disciplines to solve real-world problems and projects with the aim of shaping the total learning experience (Xu et al., 2022).

Conversely, many countries have not successfully implemented the recommendations and concepts of integrated and holistic STEM education for several reasons (Blackley & Howell, 2015; Freeman et al., 2019; Oh, 2023). A case-to-case analysis revealed that the countries which are better ranked in STEM education are those that have developed strategic national STEM policy frameworks. These policy frameworks provide a space for centrally driven and funded

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programmes, including curriculum reform at all levels and new teaching standards (Gonzalez & Kuenzi, 2012; Yan et al., 2024)). These countries have also formulated a comprehensive set of strategies to achieve their STEM goals. They aligned their STEM standards, assessments and requirements with workforce expectations, enhanced student achievements in STEM disciplines and strengthened the internal capacity of educational institutions to improve the teaching and learning of STEM subjects to uplift the quality of the STEM teaching workforce. Additionally, they identified and scaled best practices in STEM education to better prepare students for STEM-related occupations. They also initiated actions to broaden the participation of underrepresented groups, such as girls, in STEM studies and careers. Another priority was to engage students across all educational levels in cross-disciplinary projects (Blackley & Howell, 2015; Freeman et al., 2019; Oh, 2023; Thiry et al., 2023).

STEM education in the Global North and South

Mudaly and Chirikure (2023) and Wolff et al. (2022) revealed that the success of STEM education is much higher in high income and developed countries as compared to the low income developing and underdeveloped countries, giving rise to speculations that STEM education is favoring the North countries as compared to the South countries. They explained that the lack of appropriate STEM education in these countries can be attributed to several factors. Despite the evolution in the conceptualisation of STEM education, the focus is still on specialised or discrete STEM disciplines rather than embracing an integrated approach. Additionally, emphasis is still on solving problems correctly rather than creatively, limiting the development of critical thinking and 21st century skills. Moreover, the education systems in these countries are still prioritising tests, grades, college admission, degrees, and factual competencies, rather than fostering a deeper understanding and application of STEM concepts.

There is increasing debate on the impacts of the STEM education, as conceptualised by the global North, on the countries of the global South. One school of thought believes that the future of any country, independent of being part of the North or South, depends on the STEM education policies to support the required STEM workforce. The success of Rwanda is often cited, where the country has recognised the significance of STEM education and subsequently increased efforts towards reviewing the country's education curriculum and at all levels. However, a second school of thought believes that STEM education, as conceptualised by the North, has a political agenda for the rich and developed countries to maintain their economical supremacy and control over the world. They therefore advocate for a STEM education for the South by the South to legitimately position themselves at the competing edge with the Northern countries.

Frameworks underpinning STEM education

There is a challenge in selecting theoretical and conceptual frameworks for STEM education research because of two main reasons. Firstly, there are no universally accepted set of

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frameworks to guide STEM education research and secondly, the field boasts a rich abundance of diverse theoretical perspectives informing research endeavours (Bybee, 2013). It should also be noted that the alignment of such frameworks is usually positioned within the disciplinary practice of the fields that are inevitably heterogeneous (varies from context to context). However, the Framing Triangle theoretical framework, described by Cohen et al. (2003), Ball and Forzani (2007) and Sujarwanto et al. (2021), was used as a lens to capture STEM conceptions from a policy, cultural and values perspectives.

In addition to the Framing Triangle framework, two other conceptual frameworks which spouse the Framing Triangle framework were used. The first one is the conceptual framework for integrated STEM education, developed by Kelley and Knowles (2016), which pivots around learning theories and pedagogies that require a deep understanding of the complexities surrounding how people learn and teach STEM content. The second one, developed by Ortiz-Revilla et al. (2022), is the theoretical framework for integrated STEM, which focused on the important current momentum along three axes of support namely, epistemological, psychological, and didactical, which consider the integration of disciplines within STEM.

Together, these frameworks offer multi-faceted perspectives, guiding this study. The Framing Triangle framework provided insights into the interactions and dynamics between key elements of educational practice. Kelley and Knowles' framework (2016) emphasised the need for integrated STEM education and Ortiz-Revilla et al. (2022) framework highlighted the importance of epistemological and pedagogical considerations. By drawing on these theoretical perspectives, the study comprehensively and systematically explores the conceptions of STEM education.

Methodology

This study used a desktop research methodology with a three-level analysis framework to uncover the evolution of STEM conceptions over the past decade within the STEM education literature. This three-level analysis aimed to explore the landscape of peer-reviewed papers, referred to as secondary data, in the field of STEM education, as follows:

Level 1: Identification of literature relevant to conceptions of STEM education

A systematic search was conducted to identify papers on STEM education that have been published during the last 10 years (2012-2022) in peer-reviewed academic journals. The criterion of 10 years was used to ensure that recent debates in STEM education are captured. The search engines and databases used were Google Scholar, EBSCO, Emerald, and Web of Science. The search method involved using keywords relevant to STEM education, including "STEM education," "siloed approach", "interdisciplinary education", "cross disciplinary education", and "transdisciplinary education". The search was further refined to include terms such as “conceptualisation”, “integration”, "pedagogy", "curriculum", "innovation", and "emerging trends".

Level 2: Analysis for the emergence of common conceptual themes

At this level, papers identified in stage one, were analysed to identify common conceptual themes across the literature. The associated thematic analysis involved iterative coding and categorisation of key ideas, concepts, and findings present in the literature. The iterative process began with the development of an initial set of codes derived from a comprehensive review of the literature and the research questions. The initial codes were then applied to fifty selected articles to identify recurring themes and patterns. As the analysis progressed, the codes were refined and expanded through multiple rounds of coding and recoding, allowing for the emergence of new themes. This iterative approach ensured that the coding framework was both comprehensive and flexible, adapting to the data as new insights were gained (Lim, 2024). The researchers independently coded a subset of the fifty papers and the findings were compared and discussed to resolve discrepancies and to ensure validity of data. This process facilitated the identification of overarching themes and patterns prevalent in the literature. The categorization steps involved grouping the identified themes into broader categories, which were then quantified to determine their prevalence across the dataset, termed thematic loadings. This rigorous process ensured a thorough and nuanced understanding of the major themes that emerged from the analysis (Lim, 2024).

Level 3: Deep Analysis for the emergence of new STEM-related ideas and concepts

In the third level, the narratives given in the papers within the conceptual themes identified in Level 2 were compiled and analysed to produce syntheses that were then critically analysed to identify the emergence of new STEM-related ideas and concepts. This involved deep analysis to identify nuanced perspectives and novel insights related to the themes identified in the second stage. To ensure thorough exploration, we used the method of theoretical saturation, whereby data analysis continued until no new insights or ideas emerged from the literature (Strauss & Corbin, 1998). All findings were discussed and validated by the group of researchers to ensure data validity.

This iterative process of data immersion, reflection, and refinement allowed for a comprehensive understanding of the evolving discourse and emergent trends in STEM education.

Findings

During the first level analysis, a corpus of 50 scholarly articles focusing on conceptions of STEM education, published between 2012 and 2022, were identified. In the second level of analysis, the 50 selected articles underwent systematic thematic analysis to identify the key themes or dimensions that represent the conceptions of STEM that emerged from the findings of the researchers. The analysis revealed that the key themes/dimensions that represent the central focus of the STEM conceptions were (i) STEM focus on science and mathematics, (ii) knowledge-in-use and language in-use, (iii) interdisciplinary and integrated approach, (iv) assessment, (v) teacher education, (vi) economic, societal and community, (vii) policy and (viii) culture. Figure 1 illustrates the loadings of the thematic analysis, representing the percentage of articles focusing on each identified theme. These themes encapsulated the core ideas and perspectives that underpin the conceptualisation of STEM education across the selected articles.

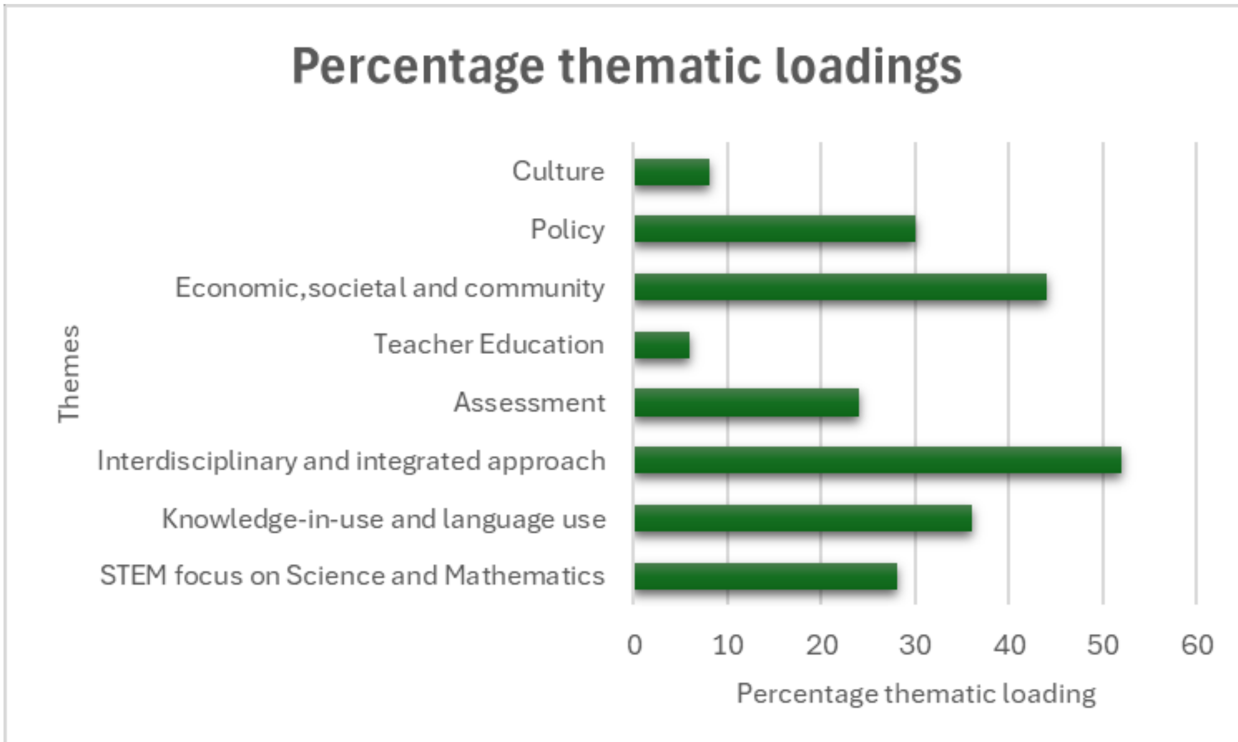

Figure 1. Thematic loadings derived from the thematic analysis

In the third level of analysis, a synthesis was prepared for each identified theme to capture the essential insights derived from a set of identified articles. Table 1 presents the themes/dimensions identified in the second level of analysis. The table also provides the corresponding set of articles that were analysed to prepare the comprehensive synthesis for each identified theme.

Table 1.
Themes and comprehensive syntheses derived from the thematic analysis.

Themes	Selected publications	Synthesis
STEM focus on science and mathematics	• Ahmed (2016) • Breiner, et al. (2012) • Bybee (2010) • Hoachlander and Yanofsky (2011) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Marginson et al. (2013) • Mcdonald et al. (2016) • Mumcu et al. (2022) • Sanders (2009) • Wang et al. (2011) • Widya et al. (2019) • Williams P J (2011) • Xu et al (2022)	Though STEM education focuses on the integration of science, technology, engineering, and mathematics, several studies expounded the role of mathematics and science as the drivers of STEM education. Mathematics and science play important roles in (i) preparing students for future careers in STEM fields, (ii) developing critical thinking skills and problem-solving abilities, (iii) encouraging students to think analytically and to use evidence-based reasoning to support their arguments, (iv) using mathematical skills in real-world contexts, (v) promoting the use of data and statistics to make informed decisions, among others. The role of mathematics and science in STEM education has evolved over time, from initially a supporting role to a fundamental role in STEM education. One reason for this shift is the growing recognition of the importance of mathematical thinking and scientific investigative skills in the modern world, as key skills for the future workforce and to address local and global challenges. Mathematics is not just a collection of formulas and equations, but a way of thinking about the world, where emphasis is on the use on the use of logic, abstraction, and quantitative reasoning to solve problems and make sense of complex phenomena. Mathematics is a foundational discipline that underlies many other fields such as science, engineering and technology, thus remains a key area that supports the interdisciplinary and integrated nature of STEM education. Furthermore, the increasing use of technology in today's world calls for an increased demand for mathematical skills. Many technological innovations, including machine learning algorithms and computer simulations, rely heavily on mathematical models and algorithms. As far as science is concerned, it remains key for understanding natural phenomena and addressing current and future challenges such as climate change, energy crises, food security, and emergence of new epidemics/pandemics among others.
Knowledge-in-use and language in-use	• Ahmed (2016) • Akgündüz et al. (2022) • Archer et al. (2022) • Aydin and Cinkaya (2018) • Costa et al. (2022) • Ismail Z (2018) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kayumova et al. (2019) • Marginson et al. (2013) • Margot and Kettler (2019)	Knowledge in-use and language in-use are key themes in STEM education. These allow students to apply their knowledge in practical ways, as it promotes a deeper understanding of the subject matter and enhances the relevance of STEM education to real-world problems. Language in-use is also emphasised, where students are encouraged to use language to (i) explain concepts and ideas, (ii) promote clarity and precision in communication and (iii) enhance the ability of students to communicate their ideas effectively. The way that knowledge is used in STEM education has evolved significantly over time, reflecting changes in the way

Themes	Selected publications	Synthesis
	• Mumcu et al. (2022) • Murphy et al. (2019) • Ortiz-Revilla et al. (2022) • Reynante et al. (2020) • Weyer and Erba (2022) • Widya et al. (2019) • Williams P J (2011)	educators conceptualise the integration of science, technology, engineering, and mathematics. Initially, STEM education was focused on developing specific knowledge and a set of discrete skills within each discipline, without focusing on how this knowledge and skills could be integrated to solve real-world problems. Thus, knowledge in STEM education was often fragmented, discipline-specific, and disconnected from real-world applications. However, with the advent of integrated STEM education and the need to integrate different fields to address complex problems, a shift in the way knowledge is used in STEM education was noted. The focus has shifted towards cross-cutting concepts that cut across multiple disciplines. Knowledge in STEM education has also evolved with the advances in technology and the increasing availability of data. The language used in STEM education has evolved significantly over time. Initially, language in STEM education was primarily focused on teaching language skills discretely within its discipline, with little attention paid to how these skills could be integrated to solve real-world problems. Language in STEM education was only limited to mastering the jargon and conventions of the field. However, with the evolution of STEM education from a discrete disciplinary approach to an interdisciplinary and integrated approach, the role of language in STEM education has changed. In fact, the language used in STEM education has become more accessible and inclusive over time, with educators recognising the importance of engaging all students in language. This has led to a greater emphasis on the use of language (i) to explain complex concepts, (ii) to use analogies and metaphors to make STEM concepts more accessible and understandable, and (iii) for development communication skills that prepares students for the world of work. As STEM fields become more interdisciplinary and collaborative, the ability to communicate effectively across different fields and with different stakeholders becomes increasingly important.
Interdisciplinary and integrated approach	• Ahmed (2016) • Akgündüz et al. (2022) • Brown et al. (2017) • Costa et al (2022) • Irwanto et al. (2020) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kocabas et al. (2016) • Kocabas et al. (2020) • Laboy-Rush (2011) • Lesseig and Slavit (2019) • Li et al (2020) • Marginson et al. (2013) • Margot and Kettler (2019) • Mcdonald et al. (2016)	The interdisciplinary and integrated approach in STEM education involves integrating concepts, skills, and knowledge across different disciplines to address complex problems. These require educators to move beyond the traditional boundaries of individual disciplines and to focus on the connections and relationships between different fields. The evolution of the interdisciplinary and integrated approaches in STEM education has been driven by several factors, including technological advancements, globalisation, and changing societal needs. Moreover, the interdisciplinary and integrated approaches in STEM education have also been shaped by changes in the way that STEM fields themselves are evolving. As fields such as biotechnology, nanotechnology, AI and materials science continue to develop, they are increasingly reliant on knowledge and skills from multiple disciplines. This has led to a greater emphasis on

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Themes	Selected publications	Synthesis
	• Milner-Bolotin M (2018) • Mumcu et al. (2022) • Murphy et al. (2019) • Ntemngwa and Oliver (2018) • Ortiz-Revilla et al. (2022) • Roehrig G et al. (2022) • Sanders (2009) • Stains et al. (2018) • Stohlmann (2018) • Sujarwanto et al. (2022) • Xu et al. (2022)	interdisciplinary approaches in STEM education to prepare students for these emerging fields and future careers.
Assessment	• Ahmed (2016) • Freeman B (2014) • Holincheck and Galanti (2022) • Kalolo (2016) • Kayan-Fadlelmula et al (2022) • Kocabas et al. (2020) • Li et al. (2020) • Marginson et al. (2013) • Margot and Kettler (2019) • Sujarwanto et al (2022) • Widya et al (2019) • Williams P J (2018)	Teachers identify challenges in assessment tools, planning time, and STEM knowledge. Lack of standardised classroom assessments to gauge understanding of diverse concepts are insufficient, and concerns arise about individual assessment with group projects. The debate is also centered around effective formative assessment strategies in STEM education, which take into consideration assessment of competencies including the 21st century skills, such as digital and problem solving, but also wellbeing. Studies have also shown that STEM education coupled with effective assessment of STEM competencies also addresses low scores in international assessments like TIMMS and PISA and students' low interest in science. For instance, Korea introduced STEAM education coupled with assessment of STEM competencies to enhance learning quality, focusing on convergent thinking, creativity, and character development. America's rankings in PISA and TIMSS are lower than some developed countries, with Mathematics' and science teaching quality stagnant, while ranking is being improved for other countries which include those who has adopted STEM education. In fact, STEM research funding has influenced non-western countries' adoption, such as Saudi Arabia, Malaysia, Korea and Thailand. Effective professional development programmes for STEM teaching and assessment are essential to enhance teachers' attitudes towards science and meet professional requirements.
Teacher education	• Dare and Ring-Whalen (2021) • Li et al. (2020) • Marginson et al. (2013)	Teacher education is essential to build capacities of educators and pupils to promote STEM education. There is a strong focus of STEM education practices which are research-based such as inquiry-based learning. Rather than simply teaching students a set of facts or procedures, STEM educators are now focused on developing students' ability to ask questions, investigate problems, and develop evidence-based solutions. This has also led to a greater emphasis on the use of scientific inquiry, engineering design, and other problem-solving approaches in STEM education. STEM education is informed by professional roles and contexts as it creates the necessary space for stakeholders such as teachers, students among others to raise questions about the coherence of STEM and how it makes sense in different ways.

Themes	Selected publications	Synthesis
		Researchers reported that planning for and implementing STEM education requires a professional dialogue among stakeholders to create a collective sensemaking and thus this dialogue among stakeholders from different contexts and professional roles is critical where issues related to STEM teaching and learning, curriculum planning and opportunities for students in terms of further learning and employability would be discussed. The trend in STEM literature strongly put forward that STEM education distinguishes itself from the single subject-based teaching and learning. In countries such as US, Canada, Australia, Taiwan and some countries in Asia, there are most collaborations among authors in STEM education research, the trend is now geared towards establishing collaborations across countries. A triadic functioning model of a theoretical framework to integrate STEM education has been proposed. This model comprises three axes, namely epistemology, didactic and psychological. The epistemological axis lays emphasis on teaching -learning process as a continuous problem solving. The psychological axis provides the learners with diverse opportunities or contexts to provide them with opportunities to manage a set of operational invariants, to develop, and to verify schemes. The didactic axis lays importance in representations and obstacles as a form of knowledge, which traditionally does not happen in single subject teaching and learning. This triadic model will help to move towards a humanistic educational contextualisation to integrate STEM education. Three key factors need to be considered when attempting to integrate STEM in teaching and learning at schools. Lack of engagement of students in early years of compulsory schooling (9 years), second implementing effective pedagogical practices to increase student interest and motivation and to develop 21st century competencies and thirdly the role of the teacher is critical in positively affecting students' attitudes and motivation.
Economic, societal and community	• Akgündüz et al. (2022) • Archer et al. (2022) • Aydin and Cinkaya (2018) • Freeman B (2014) • Gonzalez and Kuenzi (2012) • Ismail Z (2018) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kayumova et al. (2019) • Kocabas et al. (2020) • Lesseig and Slavit (2019) • Margot & Kettler (2019) • Mcdonald et al. (2016) • Murphy et al. (2019) • Ortiz-Revilla et al (2022)	Social and economic rationales are key to initiate and sustain STEM education in schools. Coordination and integration of STEM activities will provide a manpower to deal with the contemporary and emerging nature of business and industry. Researchers have introduced a framework referred as informal STEM learning (ISL) settings which according to him can provide an entry point for young people who have not previously been engaged in STEM learning at schools. This framework drawing on STEM capital and sociological conceptual lens aims to capture equitable youth outcomes by foregrounding issues of complexity, power and injustice. Five equitable outcome areas were identified, namely, STEM learning, skills, knowledge; STEM attitudes and interests; STEM path-making and progression; STEM identity and identity work and finally critical STEM agency. The first two spouse the STEM capital whereas the last three align with the sociological lens.

Themes	Selected publications	Synthesis
	• Ortiz-Revilla et al. (2019) • Sujarwanto et al. (2022) • Tang and Williams (2019) • Weyer and Erba (2022) • Widya et al (2019) • Williams P J (2011) • Xu et al. (2022)	The differences among the disciplines which constitute the STEM umbrella posits the distinction between STEM literacy and STEM literacies. STEM literacy refers to (STEM for all) all students—whether or not they pursue careers in science, will be consumers of news and information on STEM issues that will directly affect their lives. STEM literacies, drawing on UNESCO "plurality of literacy" (2004), emphasises the varying linguistic, cognitive and epistemic dimensions of the disciplines which is more appropriate in capturing the wide range of skills and emphasis related to specialised professions (Tang and Williams, 2019). This "plurality of literacy" recognises that there are "many practices of literacy embedded in different cultural processes, personal circumstance and collective structures". Therefore, this distinction of STEM literacies from the singular STEM literacy is key to interpreting, critiquing, and creating the different kind of cognitive and metacognitive processes used across the disciplines and in multiple communities and educational contexts.Practices from a single subject area may provide a framework to integrate the various STEM-related subjects though this can be influenced by the content knowledge. Each discipline has its own distinct epistemologies. While these epistemological frameworks inform the types of practices, they also orient practitioners toward different ways of thinking and understanding. (Brandon et al 2020).
Policy	• Ahmed (2016) • Akgündüz et al. (2022) • Archer et al. (2022) • Freeman B (2014) • Holincheck and Galanti (2022) • Kalolo (2016) • Kayumova et al. (2019) • Li et al. (2020) • Murphy et al. (2019) • Ortiz-Revilla et al. (2022) • Reynante et al. (2020) • Sujarwanto et al. (2022) • Weyer and Erba (2022) • Williams P J (2011) • Xu et al (2022)	STEM education in some North countries have not been able to prepare students to become workforce needed to maintain their competitive edge in the globalised world, due to lack of appropriate STEM policy. Three key comparisons among countries on STEM education success based on their legislative and policy framework supported with organisations and structures to coordinate the implementation. These are STEM literacy (in breadth), STEM excellence (in depth) and STEM inequity (redressing systemic inequities).
Culture	• Marginson et al (2013) • Kayumova et al (2019) • Otiz-Revilla et al (2022) • Kayan-Fadlelmula et al (2022)	Culture plays a significant role in shaping and influencing STEM education and participation across different contexts. Different cultural factors such as social interaction, educational practices, gender norms and indigenous perspectives, impact the effectiveness and accessibility of STEM education and career pathways. There is a need to integrate cultural insights and adapt teaching methods to align with the cultural contexts of students and educators, fostering more equitable and effective STEM learning environments.

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In the third level of analysis, the themes and their corresponding syntheses were subjected to further scrutiny and qualitative analysis. These led to the emergence of novel and nuanced ideas, perspectives, and concepts pertinent to the STEM conceptions discourse. The emergent themes identified were as follows:

Theme 1: Compartmentalised multidisciplinary against integrated approaches

One of the most pertinent discourses around STEM conceptions remains one's positionality concerning the compartmentalised versus integrated approaches to STEM education (Sanders, 2009). In fact, STEM education has evolved significantly over time leading to two ideological stances. The first stance focuses on developing specific knowledge and skills within each STEM discipline, that is science, technology, engineering and mathematics, without focusing on how this knowledge and skills could be integrated to develop concepts and to solve real-world problems (Bybee, 2010; Hoachlander & Yanofsky, 2011). Thus, knowledge and skills remained was fragmented, discipline-specific, and disconnected from real-world applications. The second ideological stance, commonly referred as integrated STEM (iSTEM), is aligned to interdisciplinary learning where different fields are brought together to address complex problems. Several articles have showcased the use of the iSTEM approach by educators, where greater emphasis is laid on cross-cutting concepts, that is concepts that cut across multiple disciplines (Kocabas et al., 2016; Li et al., 2020; Stohlman et al., 2014). However, analysis of the scholarship revealed that though most recent publications showcase increasing enthusiasm for iSTEM, compartmentalised multidisciplinary STEM education remains the persistent approach of learning in most educational settings around the world. We argue the choice for compartmentalised or iSTEM approach may depend on contexts from policies, capacity of teachers across all STEM related disciplines, and curriculum development perspectives.

Theme 2: Dominance of disciplines

The second pertinent debate around STEM education is the dominance of disciplines within STEM education. While the latter is designed as an integrated approach where science, technology, engineering, and mathematics are brought together as a cohesive entity to solve real-world problems, the findings exhibited a discernible emphasis and even a dominance on mathematics and science.

The dominance of disciplines is supported by Kristensen et al. (2024) and Shahali and Halim (2023), who explained that there is a prevalent trend in STEM curricula and instructional practices, where mathematics or science often occupies a central position due to its foundational importance and applicability across various STEM disciplines (Tang & Williams, 2019). Numerous studies highlighted the pivotal role of mathematics and sciences in fostering critical thinking, problem-solving skills, and quantitative reasoning essential for success in STEM fields.

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In fact, the role of mathematics and sciences within the framework of STEM education has undergone a notable transformation over time, transitioning from a supporting role to assuming a foundational position (Mcdonald et al., 2016). This shift can be attributed to the growing importance of mathematical thinking and scientific investigative skills in contemporary society, its role as a requisite skill for the future workforce and its foundational role in other disciplines such as technology, and engineering (Boaler, 2016; Hiebert & Wearne, 1996). This shift underscores the dynamic interplay between mathematics or science and STEM education, reflecting the evolving landscape of contemporary education. Additionally with an increasing demand for engineering, the design component of the STEM umbrella make take a leading role in the STEM education agenda.

Theme 3: Extending the core disciplines in STEM

The analysis showed extension of the core disciplines within the realm of STEM education. The extension implies a broadening of the traditional boundaries that delineate the core domains of STEM, to incorporate additional disciplines into the STEM equation. It underscores a shift towards a more integrated and holistic approach to STEM education, aimed at fostering innovation, creativity, and adaptability in addressing complex societal challenges (Breiner et al., 2022; Bybee, 2010; Revilla et al., 2022) One example of extension is the integration of language in-use in STEM education leading to the development of STEM variant STREAM, with the additional R standing for reading/writing (Hoachlander & Yanofsky, 2011). In fact, at its conception, language in STEM education was only limited to mastering the jargon and conventions of the field. However, the role of language in STEM education has changed to become more accessible and inclusive over time, with educators recognising the importance of engaging all students in language (Archer et al., 2022; Murphy et al., 2019). This has led to a greater emphasis on the use of language to explain complex concepts, to use analogies and metaphors to make STEM concepts more accessible and understandable, and to develop communication skills that prepare students for the world of work. As STEM fields become more interdisciplinary and collaborative, the ability to communicate effectively across different fields and with different stakeholders became increasingly important (Kayumova et al., 2022, Murphy et al., 2019). This extension of STEM towards non-scientific disciplines, such as language and arts, might help to promote academic writing and creativity respectively.

Theme 4: Policies and practices for STEM education

Existing policy documents make references to promoting STEM education at different levels in view of providing the required workforce for the present generation and beyond. However, the findings revealed that these are fragmented policies, which do not reflect a systemic or holistic policy for STEM education. Consequently, these existing policies are not sufficient to equip the present and future generations with the necessary STEM competencies needed to create a workforce that will maintain a competitive edge in a globalised world (Kocabas et al., 2020). Today's leading debates include the need to re-orient STEM policies and practices towards achieving the workforce for STEM competencies. These policies and practices should look at the breadth of coverage of STEM in the education policies and practices, referred to as STEM literacy or STEM excellence (STEM in depth) as well as addressing inequities in terms of accessing quality STEM education (STEM inequity). STEM policy making and formulation might become a more dynamic process to incorporate changes and updates in the said policies.

Theme 5: Variations in the implementation of iSTEM education

In addition to the discourse of one's positionality between compartmentalised versus integrated approaches to STEM education, another pertinent discourse that emerged from the findings is the variation in the implementation of iSTEM education. One notable variation identified was the differing approaches to the implementation of iSTEM at the classroom level, in relation to students' engagement, pedagogical practices used, and the role of teachers (McDonald, 2016).

Another variation was the theoretical framework(s) used to guide the implementation of iSTEM education. An example of a functioning framework for the implementation of iSTEM education in teaching and learning is the triadic model proposed by Ortiz-Revilla et al (2022). This framework comprises three axes, namely epistemology, didactic and psychological. The epistemological axis emphasises the teaching-learning process as continuous problem-solving. The psychological axis emphasises on the learners with diverse opportunities or contexts to provide them with opportunities to manage a set of operational invariants. The didactic axis lays importance in representations and obstacles as a form of knowledge, which traditionally does not happen in single subject teaching and learning. This triadic model provides a humanistic educational contextualisation to integrate STEM education. Another example of framework commonly used was the Informal STEM learning (ISL) framework proposed by Archer (2022). It provides an entry point for young people who have not previously been engaged in STEM learning at schools. Drawing on STEM capital and a sociological conceptual lens, this framework aims to capture equitable youth outcomes by foregrounding issues of complexity, power and injustice and thus consolidate the democratic nature of STEM education and education at large.

Theme 6: Epistemological considerations for STEM education

Another interesting discourse in STEM education is the difference in epistemological considerations underpinning the distinction between STEM literacy and STEM literacies. STEM literacy, that is STEM for all, refers to all students regardless of whether they pursue careers in science, as they will engage with information on STEM issues that directly impact their lives.

STEM literacies, which refers to the plurality of literacy (UNESCO, 2004), states that the varying linguistic, cognitive and epistemic dimensions of the disciplines are more appropriate in capturing the wide range of skills related to specialised professions (Tang & Williams, 2019). This plurality of literacy recognises many practices of literacy embedded in different cultural processes, personal circumstances and collective structures. Therefore, this distinction of STEM literacies from the singular STEM literacy is key to interpreting, critiquing, and creating the different cognitive and metacognitive processes used across the disciplines and in multiple communities and educational contexts.

The findings also revealed that practices from a single subject area may provide a framework to integrate the various STEM-related subjects though this can be influenced by the content knowledge. Each discipline has its own distinct epistemologies. While these epistemological frameworks inform the types of practices, they also orient practitioners toward different ways of thinking and understanding (Brandon et al., 2020). The interesting point here is that it provides more than one entry to engage in the STEM education processes.

Theme 7: STEM for employability

The global emphasis on STEM education extends beyond innovation to the cultivation of a highly skilled workforce primed for the demands of modern industries. There are ongoing efforts throughout the world to enhance educational standards, with a particular focus on fostering problem-solving abilities, creativity, and critical thinking which are all essential attributes in today's innovation driven economy (Xu et al., 2022; Weyer & Erba, 2022). The success of these endeavours also relies on significant investments in the professional development to attain the relevant STEM employability competencies. Besides, there is an international call for more students to pursue STEM programmes at the tertiary level, which can help them transit into STEM-related research careers (Freeman, 2015). This necessitates programmes that ensure STEM literacy at the secondary level so that a solid foundation is developed for future educational pursuits and career opportunities in STEM.

Entrepreneurship and the corporate sector have pivotal roles in the employment landscape, driving both economic growth and innovation. This role will have to be extended to support the education sector hence address the existing mismatch between the corporate employability requirements and the supply from the education sector. Programme/ curriculum development committees could consider having representatives from the corporate/industry sector.

Theme 8: Realigning Assessment in STEM Education

Assessment in STEM education is crucial for determining the preparedness of students and the workforce to meet the demands of a rapidly evolving global landscape. In current education, there is a dominance of summative assessment, both at international and national levels, which focuses mainly on the cognitive aspects of learning. By its nature, STEM education encompasses a set of competencies which are marginalised when it comes to assessment of learning. We, therefore, argue that to ensure a proper equation between an elaborated STEM and assessment, the assessment practices should be foregrounded in the evaluation of STEM competencies from early years to higher education (Kocabas et al., 2016; Widya et al., 2019). Thus, an assessment framework for STEM competencies would help to foreground this proper equation.

STEM Education Conceptions Framework

Figure 2 shows the 'STEM education conceptions framework' that has been developed from conceptions that emerged from the systematic analysis of the scholarship on conceptions of STEM education.

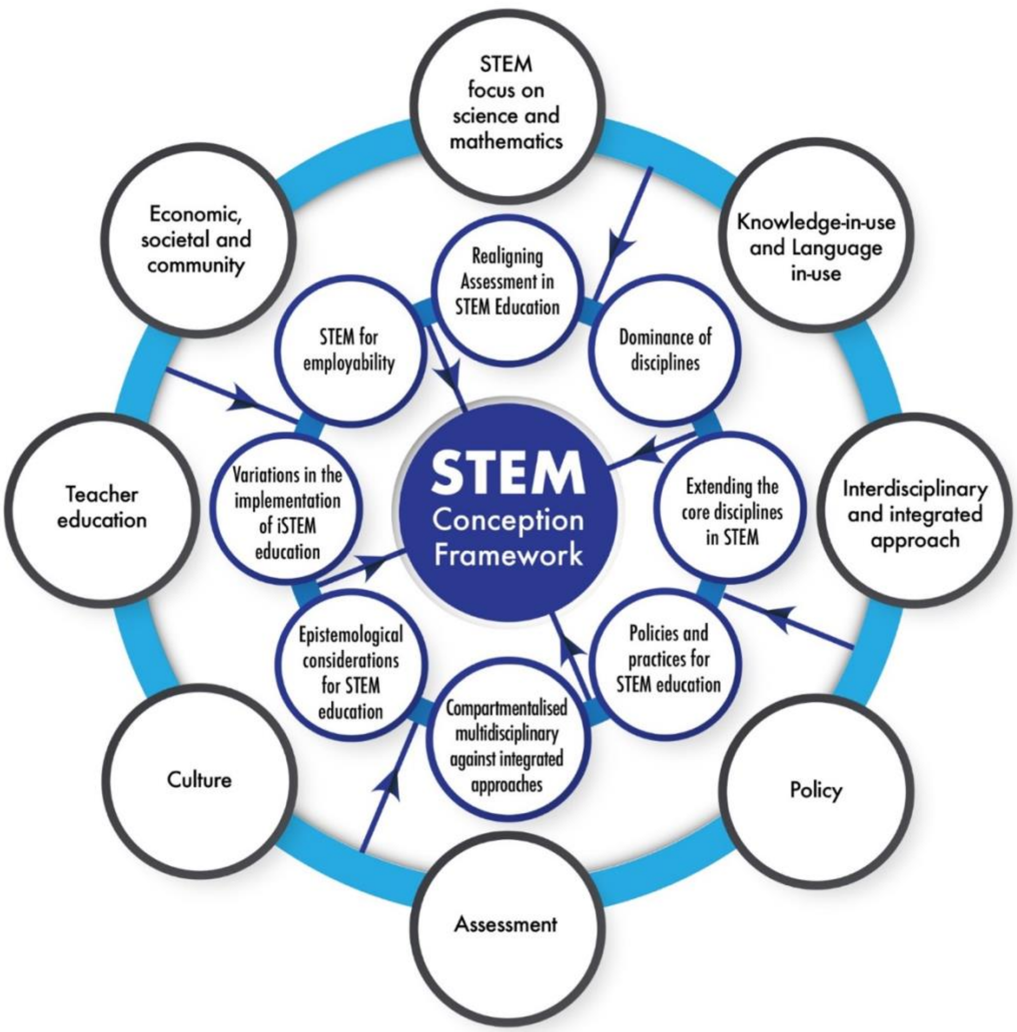

Figure 2. STEM Education Conceptions Framework (SECF)

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Discussion

STEM education has assumed significant importance related to debates on educational reform efforts (Holmlund et al., 2018) in the Global North and South. STEM education in both Global North and South has become a figure of rhetoric in education driven by the dynamic duo - global economy and workforce needs (Ahmed, 2016). The arguments thereof are reasonable as appropriate STEM education has a crucial role in enhancing economic fortunes through a highly educated labor force, and thus increasing the national competitiveness (McDonald, 2016).

Notwithstanding, as Willians (2011) posits, there is a need to proceed with caution, especially when the focus is on meaningful iSTEM education instead of the traditional compartmentalised STEM education. We therefore argue that the development of STEM policies and their implementations should be preceded by a systematic analysis of the conceptions of STEM education and the issues associated with it. Amid arguments that it is not driven by education rationale per se (Williams, 2011) and countries implement it differently (Roehrig et al., 2022), we need to address the issue of what constitutes STEM (Ortiz-Revilla et al., 2022), and a lack of complete unison concerning its global attributes as an innovation (Holmlund et al., 2018). These issues, particularly the latter, are important as they will map out the way forward on how STEM education is conceptualised from national to global levels and critically analyse how it is currently measured especially when STEM education is still conceptualised differently (Xu et al., 2022).

We acknowledge that considerable research has been done on country specific STEM education (Marginson et al., 2013), key definitions of STEM (Hasanah, 2020; Marginson et al., 2013), STEM variations such as STEAM (Anderson, 2021; Belbase et al., 2021; Weyer & Dell'Erbs, 2022), STEM policies, commitments and practices (Kalolo, 2016), and most importantly on STEM frameworks (Kelly & Knowles, 2016; Ortiz-Revilla et al., 2021). Nevertheless, this study has focused on the most current and pertinent discourses around the global conceptions of STEM education. We believe that our findings and the developed 'STEM Education Conceptions Framework (SECF)' will provide a collective uncharted terrain for research and pave the way for meaning and understanding STEM education in the Global South and North countries, which have contrasting outlooks in terms of developing industrial base, education pathways, teacher characteristics and STEM opportunities.

In fact, the development of a STEM education conception framework thereof is crucial for several reasons. Firstly, it provides a structured and coherent understanding of the complex nature of STEM education, which is an amalgamation of various disciplinary approaches, pedagogical strategies, and educational policies (cf. Kelly & Knowles, 2016; Aguilera et al., 2024). The framework encapsulates these diverse dimensions into a unified model that can guide educational stakeholders including educators, school leaders, researchers, and policymakers in understanding and implementing effective and meaningful STEM education practices today. Theorising STEM education in contemporary society (marked by technological and economic developments that call for frameworks for rethinking STEM education praxis [Sujarwato et al., 2021]), George Fomuyan (2020) calls for adapting frameworks for application in the era of the fourth industrial revolution where STEM education practices should mould scholars with 21st-century skills, hence prepared for such era's workplace. After all, 21st-century virtual reality, among others, has already attracted practitioners' interest (Christopoulos et al., 2020). It is worth noting here that "most of the pedagogical models proposed for STEM education…focus imprecisely on the methodological dimension of the STEM approach… [hence a need for] a robust epistemological and pedagogical framework…[essential] for the design of coherent and viable didactic model" (Aguilera et al., 2024, pp. 2). By identifying and describing the current and most pertinent discourses around STEM education, such as the compartmentalised versus integrated approaches, dominance of disciplines, variations in the implementation of iSTEM education, epistemological considerations for STEM education and variations in and the role of policies and practices, the framework facilitates a clearer comprehension of how these elements interact and influence each other. The aspect of interdisciplinarity, does not only pinpoint STEM's influence in the collective solving of practical problems but also points to the associated "…generation of new codes, common understanding, methodological conceptual agreements, and ways of formalizing exchanges…a leap that, when achieved, is irreducible to the participating disciples" (Ortiz-Revilla et al., 2022, pp. 385-386). The SECF therefore makes provision to identify and uncover the complex interconnectedness within a broader perspective of STEM education.

Secondly, SECF is vital for addressing the variations in STEM education practices observed across different contexts or countries. As Marginson et al. (2013) reported that despite varying discipline grouping that fall under the ambit of STEM, mathematics and science remain fundamental to both narrow and broad conceptions, SECF framework provides a systematic structure that may be used to analyse these variations, enabling stakeholders to identify best practices, adapt interventions to specific contexts, and enhance the consistency and quality of STEM education across diverse educational settings.

Thirdly, the inclusion of aspects such as STEM for employability and the impact of economic, societal, and community factors underscores the framework's relevance to broader educational and societal goals. STEM education is not merely about imparting knowledge but also about equipping students with the competencies necessary for successful careers and informed citizenship. By integrating these considerations, the framework ensures that STEM education remains aligned with the evolving demands of the workforce and contributes to societal advancement.

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However, for the successful adoption of the SECF, all actors involved in the promotion of STEM education need to have a sound understanding of iSTEM. This could be hindered by the diverse STEM conceptions which might exist among the actors within a particular country and from countries to countries. Furthermore, the SECF does not explicitly situate innovation and values in transforming practices through STEM education. The Values-based model proposed by Vedrenne-Gutiérrez et al. (2024) identified values and ethics in STEM education which are fundamental in directing science and technology policies and shaping organizational cultures to leverage innovation. This values-based model is implicitly captured across the underlying concepts within the SECF.

Conclusion

This study has come up with eight emerging themes for STEM education by drawing on STEM literature from peer-reviewed papers published over the past decade. Existing literature has revealed several frameworks for STEM education (Ball & Forzani, 2007; Cohen et al., 2003; Kelley & Knowles, 2016; Ortiz-Revilla et al., 2022; Sujarwanto et al., 2021) which was either positioned within the disciplinary practice or provided compartmentalised cultural, policy and values perspectives for STEM education or a lens to capture the complexities of interactions within the various conceptions of STEM education. The 'STEM Education Conceptions Framework, developed from the emerged discourses on STEM education provides a holistic view of conceptions allowing space for a much broader and a wide range of perspectives including epistemological, psycho-pedagogical and at the same time opening for more possibilities of connectedness thereby extending the STEM disciplines. This SECF is also crucial for advancing our understanding and practice of STEM education. The framework offers a valuable tool for educational stakeholders to navigate the complexities of STEM education and engage in meaningful STEM education. Stevenson et al. (2024) highlighted key experiences valued for helping teachers learn and integrate STEM education content. However, they stated that the complexity of STEM education and teacher learning means that different activities lead to different learnings. Our conceptual framework will provide guidance to teachers and teacher educators to include STEM-based learning at schools.

Acknowledgment

SECF developed through analysis of existing literature defined within a time frame of 2012-2022 has opened some broader perspectives, yet it could be further evolved by new emerging research ideas on STEM education research.

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RESEARCH REPORT

Supporting BIPOC Males in STEM: Insights from a Case Study on Online Peer Mentoring

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Abstract

The current study explores the implementation and impact of online peer mentee training, part of a larger online peer mentoring program, on the science, technology, engineering, and mathematics (STEM) self-efficacy, sense of belonging, and STEM identity of Black, Indigenous, and Other People of Color (BIPOC) males enrolled in STEM degree programs at a historically Black institution. Framed by Bandura's Self-Efficacy Theory, Tinto's Institutional department Model, and Social Cognitive Career Theory, it examines participants' intent to persist in their STEM degree programs and subsequent STEM careers. Using a case study design, interviews and focus groups were analyzed. Five themes were identified: Development and Solidification of Identity, Increase in Confidence, Motivation to Make an Impact, Belonging, and Persistence and Retention through Developing Skills. The study is significant as it attends to the dearth in research that examines BIPOC males' experiences in an online peer mentoring program while enrolled in STEM degree programs at historically Black colleges and universities (HBCUs). The findings provide insight on one method for supporting the participation of BIPOC males in STEM—an historically underrepresented population within STEM degree programs and fields. The findings inform institutions seeking to broaden participation within STEM fields while simultaneously supporting the retention of underrepresented populations in STEM degree programs. The findings also inform future implementations of online peer mentoring programs within HBCUs.

Keywords: *STEM, mentoring, male, BIPOC, self-efficacy, sense of belonging*

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It is projected that, by 2060, one in three Americans (32% of the total U.S. population) will identify as a race other than White (Vespa et al., 2020). The percentage of those that identify as two or more races is projected to increase by 200% (Vespa et al. 2020). While the number of Black, Indigenous, and People of Color (BIPOC) completing a baccalaureate or graduate degree in science or engineering has increased slightly over the past decade (National Center for Science and Engineering Statistics [NCSES], 2021; 2023), the percentage of such individuals earning those degrees has remained fairly steady across science and engineering fields--with the exception of computer sciences, which has experienced an almost 2% decline. The data indicates that, while BIPOC individuals have earned a larger number of science, technology, engineering, and mathematics (STEM) degrees than in years past (NCSES, 2023), the proportion of the total degrees being awarded has not kept pace with the increasing diversity of the population (Jehangir et al., 2022; Prunuske et al., 2016); thus, if not attended to, will result in further disparity (Gasman et al., 2017).

Of special importance is the participation of BIPOC men in STEM fields. For instance, 12% of the total population within the United States is composed of Black men, with Hispanic or Latino men making up 18% of the total population (NCSES, 2023). However, the NCSES (2023) reports that only 9% of the total STEM workforce within the U.S. is composed of Black men, with Hispanic or Latino men making up only 15% of the total STEM workforce. While men comprise a slightly larger portion of the STEM workforce than women (52% as compared to 48%; NCSES, 2023), the participation of men—especially BIPOC men—remains inequitable.

Mentoring, however, has been shown to support the persistence, retention, and success of students enrolled in STEM degree programs, especially among racially and ethnically minoritized populations (Mondisa & Adams, 2022) including BIPOC men (National Academies of Sciences, Engineering, and Medicine [NASEM], 2019). Importantly, mentoring can assist in diversifying those who enroll in STEM degree programs and persist in STEM fields (Mondisa & Adams, 2022). Mentoring is defined within the literature as "a process in which an experienced individual (a mentor) provides emotional and psychosocial support (e.g., listening, empathizing, offering advice, providing affirmation or an objective perspective), and helps to educate, guide, and counsel a less experienced person" (Mondisa & Adams, 2022, p. 339). Peer mentoring—one type of mentoring--defined as "a reciprocal, dynamic relationship between or among peers where one peer is usually more skilled or experienced than the other" (Rockinson-Szapkiw et al., 2021a, p. 2), has shown substantial promise in supporting STEM students (Graham & McClain, 2019; Pon-Barry et al., 2017; NASEM, 2019). Peer mentoring can be beneficial when the availability of faculty mentors is lacking (Mondisa, 2018; Wilton et al., 2021), when mentoring is needed outside of the research laboratory context, and when mentees are in need of models that are more relatable (i.e., similar stage of life, similar background, similar experiences to biases or other

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obstacles) (Mondisa & Adams, 2022; Zaniewski & Reinholz, 2016). Online mentoring can be defined as "mentoring in which all or most of the experience takes place utilizing online technology" (Rockinson-Szapkiw et al., 2021b, p. 174). Online mentoring can be beneficial when constraints such as geographic location or public health events (e.g., covid-19) create a barrier to traditional, face-to-face mentoring or when more flexibility is desired. In the post-pandemic era and with the steady increase in the use of technology, evidence-based practices that support effective online peer mentoring need to be explored.

The literature further highlights the misguided notion that successful mentoring relationships can develop organically simply because one individual is more experienced than another (Pfund et al., 2016; Sorkness et al., 2015). Indeed, the quality of the mentoring relationship can directly impact the effectiveness of mentoring practices. A large body of evidence shows that mentors and mentees need to be intentionally trained in how to engage in reciprocal and productive mentoring relationships (Pon-Barry et al., 2017; Sánchez et al., 2018; Wilton et al., 2021).

Thus, the current study is motivated by pilot research that developed and tested a model of online peer mentoring and peer mentor training and implemented it among BIPOC women at two HBCUs (see Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw & Wendt, 2020; Rockinson-Szapkiw et al., 2021b). The overall purpose of the cumulative online peer mentoring program was to broaden participation of historically underrepresented populations in STEM degree programs and STEM fields by positively influencing students' interest in STEM, self-efficacy in STEM, sense of community, STEM identity, and intent to persist in STEM. Given this goal, the current study, therefore, extended our inquiry to examine the experience of BIPOC males enrolled in an online peer mentoring program, with a specific focus on the online peer mentee training component of the overall program.

The online program consisted of three key features: peer mentoring training, peer mentoring, and community engagement through STEM Webinars and the Slack platform. The training component had eight modules on the following topics: 1) an introduction to mentoring; 2) mentee reflection; 3) skills for building and maintaining trust; 4) skills for beginning a peer mentoring relationship; 5) skills for developing a peer mentoring relationship; 6) ethics in mentoring; 7) cultural responsiveness in mentoring; and 8) skills for engaging in online peer mentoring relationships. Each of the eight online peer mentee training modules included three components: 1) a topical discussion that provided an overview of the module and the related research pertaining to the module content (Figure 1); 2) a case study that provided a demonstration of how the module content could be applied, designed purposefully to encourage motivation, emotion, and volition (Figure 2); and 3) a personal application and reflection that provided an opportunity to apply the module content to mentees' experiences (Figure 3). The

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design process and usability study aligned with the module construction has been previously reported (see Gish-Lieberman et al., 2021). Online peer mentee training was self-paced, although a suggested schedule was provided to guide mentees. While completing the online peer mentee training, participants were simultaneously asked to engage with other peer mentees within an online community hosted on the Slack platform. Further, mentees were invited to attend three one-hour STEM Webinars which featured BIPOC women who had a demonstrated record of success in a STEM field.

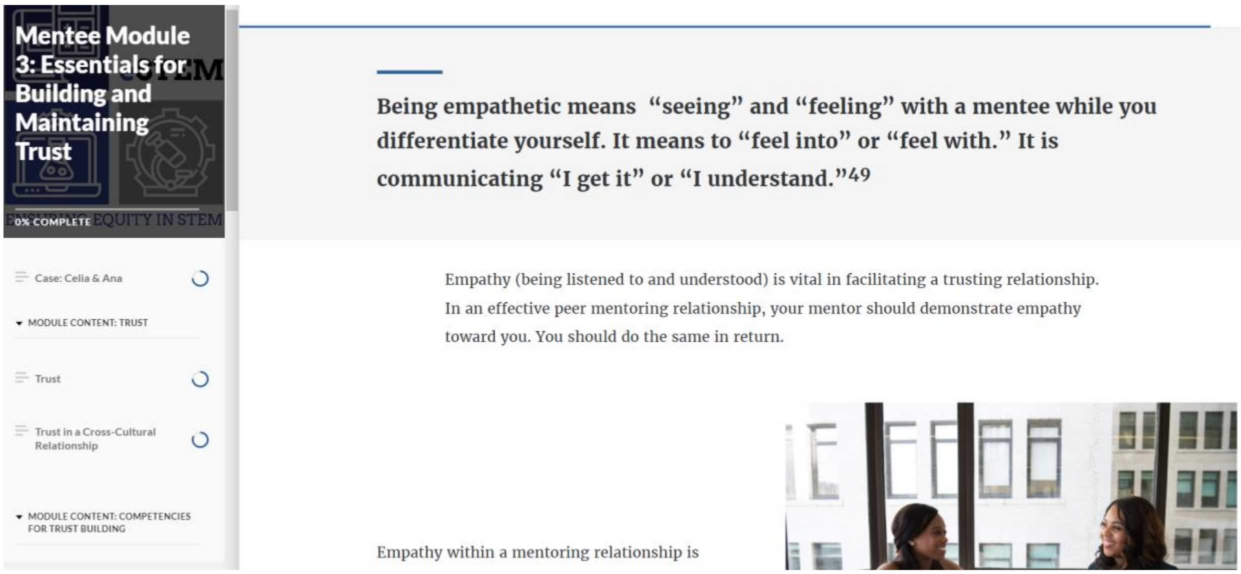

Figure 1. Screenshot of the overview component of one mentee training module

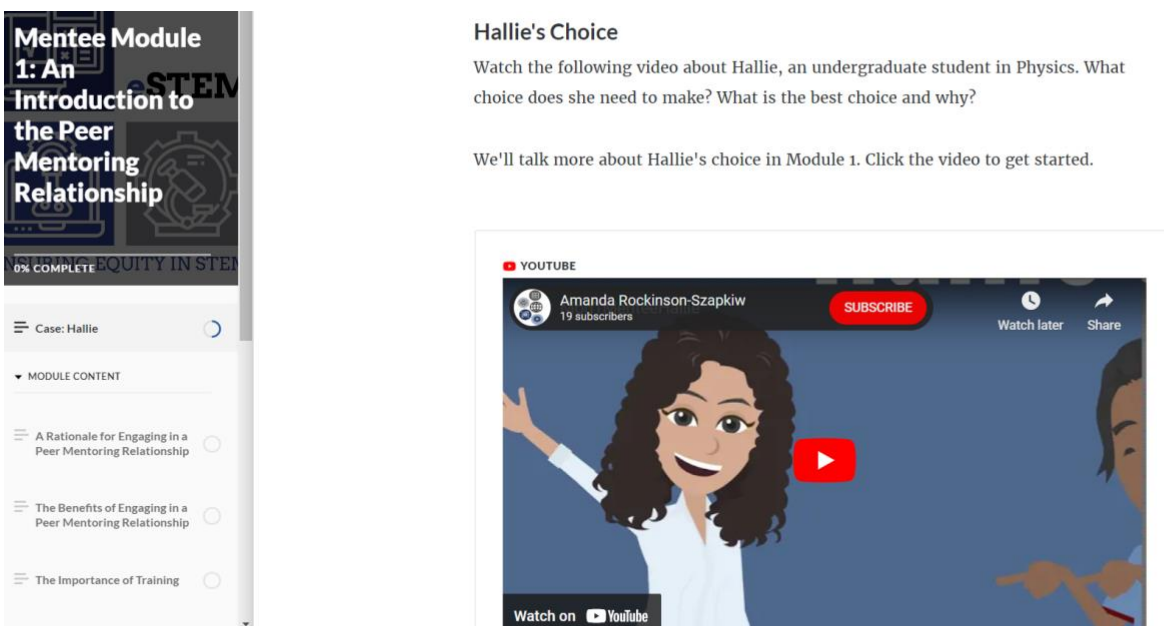

Figure 2. Screenshot of the case study component of one mentee training module

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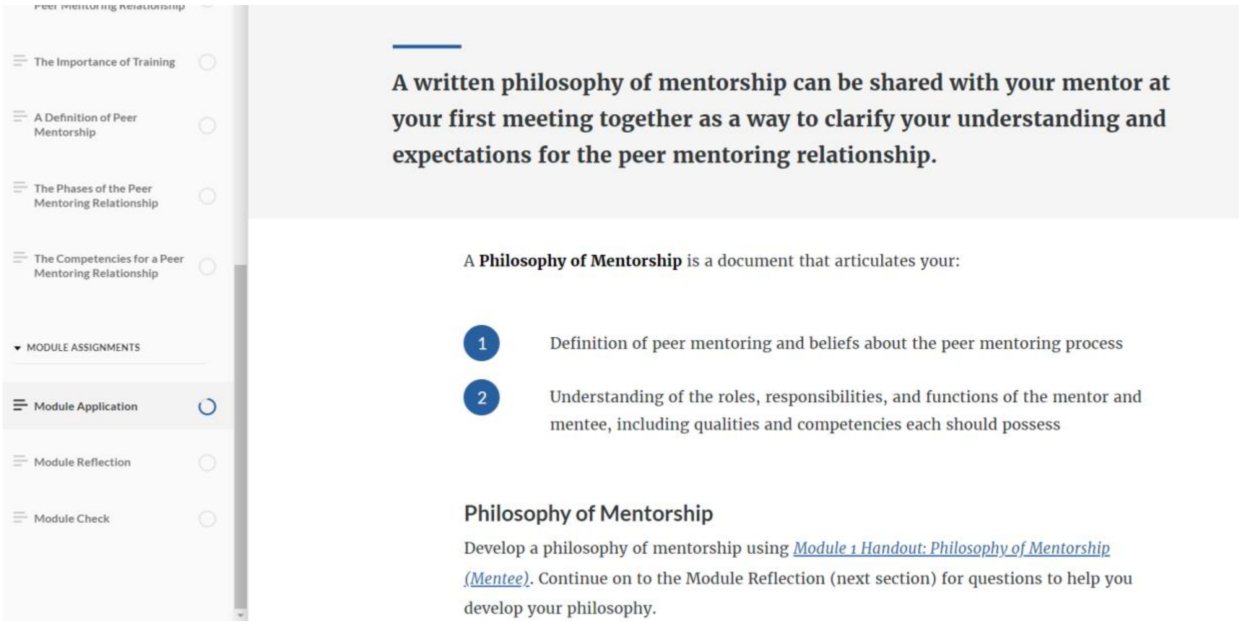

Figure 3. Screenshot of the application component of one mentee training module

Figure 4. Screenshot of one STEM Webinar

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Theoretical Framework

The overall online peer mentoring program was grounded in multiple frameworks including Tinto's (1987, 1993, 2017) institutional departure model, Bandura's (1977, 1997) theory of self-efficacy, and Lent et al.'s (1994) social cognitive career theory (SCCT).

Institutional Departure Model

According to the institutional departure model (Tinto, 1987, 1993, 2017), everyone possesses personal attributes (such as gender, ethnicity, race, and culture), familial backgrounds (such as socioeconomic status and level of parental education), and prior experiences (such as academic experiences and socio-emotional experiences). When an individual enters an institution of higher education, it is the confluence of these attributes that influences students' ability (or inability) to integrate within the institution—both academically and socially. When an individual is unable to integrate, they may experience low levels of commitment, low levels of persistence, and low levels of a sense of community and belonging (Tinto, 1975). Thus, the institutional departure model suggests that the degree to which one integrates socially and academically into a particular community will directly influence their level of persistence, commitment, and sense of belonging within that community.

Studies have shown that activities that promote integration and the development of a sense of belonging - like opportunities for social interaction, social networking, and support - can be facilitated through peer mentoring. Peer mentoring can support integration through the provision of psychosocial support (where an individual's perception of competence is enhanced), instrumental support (where engagement, development of a sense of belonging, and goal achievement are encouraged through availability of resources), and academic support (where content-area knowledge and career skills development are facilitated) (Wilton et al., 2021). When considering the online peer mentoring training used in the current study, psychosocial support and instrumental support can be facilitated by intentional skills practice (e.g., applications and reflections), exposure to like others (e.g., case studies, vignettes, and STEM Webinars), and goal setting.

Social Cognitive Career Theory

SCCT (Lent et al., 1994) demonstrates that the value an individual attributes to a particular discipline, such as STEM (Clark et al., 2016), facilitates persistence, motivation, and engagement. If a discipline is perceived as having value, an individual is more likely to be motivated to engage and persist in that field. Engagement provides opportunities to gain new skills by attempting new tasks, thus contributing to mastery experience and skills development. As a result, self-efficacy and a sense of belonging are enhanced (Bandura, 1977, 1997). Self-efficacy can be further enhanced when mentees experience social and academic integration coupled with an enhanced sense of belonging--directly influencing their decisions, engagement, and persistence and, thus, influencing STEM outcomes. Self-efficacy serves as a mediating factor for identity development (Chemers et al., 2011). When considering the online peer mentoring training used in the current study, the value inherent to participation in STEM was emphasized through orientations to specific mentoring related topics and skills, providing instruction on obtaining such skills, and providing targeted opportunities for reflection and application to personalize the experience. Value was further emphasized through interactive components, including opportunities to network with peers and attend STEM Webinars where speakers described their journey and contributions to STEM.

Identity

Mentoring has also been shown to support the development of STEM identity (Clark et al., 2016). The development of STEM identity is foundational for encouraging participation and persistence in STEM, setting up "additional processes by which individuals judge their competence and belonging" (Clark et al., 2016, p. 2). The development of STEM identity, as well as recognizing and reconciling intersecting identities, can lead to increased efficacy in goal setting, enhanced progress toward goal attainment, and more effective decision making that foster progress toward achievement of goals (London et al., 2011). In fact, identity development has been shown to predict an increased sense of belonging as well as increased levels of motivation (Clark et al., 2016).

Review of the Literature

While emerging research has explored the impact of peer mentoring on BIPOC women related to the frameworks (see Jehangir et al., 2022; Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw et al., 2021b), little research has examined the experiences of BIPOC men. Further, the literature calls for studies that specifically utilize qualitative approaches to further understand how mentoring can support the participation of minoritized populations in STEM (Jehangir et al., 2022). Importantly, understanding the contexts within which BIPOC men are effectively supported in STEM as well as interventions that can facilitate fruitful mentoring relationships are needed (Burt et al., 2019; Gasman et al., 2017; Sánchez et al., 2018).

Historically Black Colleges and Universities

Historically Black Colleges and Universities (HBCUs) have proven the ability to support the persistence of BIPOC individuals across STEM fields, producing a significant share of BIPOC graduates in STEM fields (NCSES, 2021; Thompson et al., 2016). Despite their success in supporting BIPOC students, there is a dearth of literature examining specifically how HBCUs

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support BIPOC males' STEM experiences at these institutions. Little is known about: (1) what specific initiatives, supports, and other strategies have been most effective in supporting BIPOC students' attainment of STEM degrees; (2) the relative generalizability of strategies demonstrated as effective across HBCUs (McGee, 2020); and (3) how mentoring practices at HBCUs support the persistence and retention of minoritized students (Mondisa & Adams, 2022). Further, efforts should be devoted to examining how to support BIPOC males' experiences in STEM more broadly to attempt to mitigate the challenges inherent to STEM environments that, by and large, have been "designed to attract White men who are heterosexual, abled-bodied, Christian or atheist, middle-class and above" (McGee, 2020, p. 634). STEM environments oftentimes present as chilly or hostile settings within which BIPOC men either must "emulate or embody hegemonic values, navigate an environment that is hostile to their identities, or leave the field" (McGee, 2020, p. 634). When students are excluded or unsupported because of their gender, ethnicity, or race, this "leads to a loss of diversity in STEM fields that must be addressed" (Wilton et al., 2021, p. 1).

Among the available literature, one study examined the experiences of 30 Black men in engineering degree programs to determine what factors best supported their persistence (Burt et al., 2019). The findings indicated that mentoring was one key factor, along with parental and familial support, spirituality, and religion that contributed to students' persistence. These findings are important as they demonstrate the potential utility of providing not only academic support to Black men, but also psychosocial support—both of which can be obtained through mentoring relationships (see Rockinson-Szapkiw et al., 2020; Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw et al., 2021b; Wendt & Jones, 2024). Another study examined mentoring among Hispanic students and showed a relationship between social comfort and belonging within the mentoring relationship and students' academic outcomes, including persistence (Daniels et al., 2018). These findings further support the benefits of mentoring on academic and psychosocial outcomes. Martin and colleagues' (2019) systematic review of the literature further verified the positive impact of mentoring on the success of Latinx STEM students at 2-year institutions, indicating the utility of mentoring for enhancing academic outcomes.

In the context of HBCUs, Gasman and colleagues (2017) explored how one HBCU, Morehouse College (an all-male institution), cultivated Black male achievement in STEM. They purported that the underrepresentation of BIPOC males in STEM is due to myriad factors, including lack of access to quality, rigorous K-12 education, susceptibility to negative stereotypes, and disadvantaged backgrounds. HBCUs, given their mission "to mediate and support the achievement of Black students" (p. 184), assist in mitigating the negative impacts of these factors. However, BIPOC men are still in need of mentors and quality mentoring relationships, even within the context of HBCUs (Gasman et al., 2017)—simply attending an HBCU is not sufficient in meeting the academic and psychosocial needs of BIPOC male students. It was the relationships

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with peers of the same race that were deemed essential to their success. "Same peers and faculty are perceived to be more open sources of support because oftentimes they are more sensitive to the struggles encountered by (other) Black students" (p. 184).

Supporting Students through Mentoring

Psychosocial constructs, such as social integration, fostered interest, self-efficacy, and identity development have been cited as foundational to supporting BIPOC student retention in STEM (Jehangir et al., 2022; Wilton et al., 2021). Jehangir and colleagues (2022) explained that the development of identity, especially within the context of intersectional identity, is key to supporting minoritized students' interest in and persistence in STEM. Underlying factors such as being a first-generation college student or of a lower socioeconomic class—both underrepresented within the general population but common among minoritized populations—contribute to identity. "Structural systems of dominance and subjugation related to students' marginalized social identities (e.g., gender, class, race, ethnicity, immigration status, among others) play a significant influence on the STEM participation and persistence" (Jehangir et al., 2022, p. 90) among minoritized populations.

Mentoring has the capability, however, of providing structured support that attends to social integration, interest, and self-efficacy (Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw et al., 2021b; Wendt & Jones, 2024; Wilton et al., 2021). The degree to which students receive such support plays a role in their decisions to remain within the institution and within their degree programs (Wilton et al, 2021) as well as in negotiating their identity (Jehangir et al., 2022). "Mentorship supports integration through psychosocial support, instrumental support, and academic support" (Wilton et al., 2021, p. 2)—each of which contribute to persistence. Further, mentorship can result in enhanced career outcomes including "career planning, career involvement, income, and promotions" (Saffie-Robertson, 2020, p. 567), contributing to increased career capital and generational wealth—both of which have been identified as inequitably distributed among those racially and ethnically minoritized. Mentoring is foundational for supporting diverse representation in STEM by attending to issues of retention, success, personal well-being, and bias within STEM fields (Deanna et al., 2022; Mondisa & Adams, 2022).

Despite the literature supporting the benefits of mentoring, the dearth in BIPOC individuals attaining terminal degrees in STEM (7%) compared to the total population (14%; NCSES, 2023), compounded by the dearth of BIPOC individuals serving in faculty roles at colleges and universities, can often make it difficult for students to find faculty mentors. Thus, peer mentoring may be beneficial in supporting BIPOC males' persistence and integration in STEM. In a previous pilot study that focused on broadening participation among BIPOC women enrolled in STEM degree programs at two HBCUs, findings demonstrated that online peer mentoring can support the development of interest in STEM, STEM self-efficacy, and persistence in STEM among both peer mentors and peer mentees (Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw et al., 2021b). However, in the previous study, training for effective online peer mentoring relationships was only developed and provided to peer mentors—peer mentees were not provided the same opportunity. And, perhaps most importantly, previous study included only BIPOC women—not BIPOC men. Thus, there is a need to explore the impact of experiences in online peer mentoring at HBCUs among BIPOC men. The current study, therefore, focuses on the implementation of peer mentee training to support BIPOC students enrolled in STEM degree programs at HBCUs with a specific focus on the experiences of BIPOC men.

Current Study

As aforementioned, the current study extended a peer mentoring model developed in a previous pilot study (see Rockinson-Szapkiw et al., 2021a; Rockinson-Szapkiw et al., 2021b) to understand the extent to which online peer mentee training impacts students' STEM self-efficacy, sense of community, STEM identity, and intent to persist. The current study was motivated by the following guiding questions:

- RQ1: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' STEM self-efficacy?
- RQ2: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' sense of community in STEM?
- RQ3: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' STEM identity?
- RQ4: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' intent to persist in a STEM degree program and, ultimately, their intent to pursue a STEM career pathway?

While the training modules, and the overall mentoring program, were primarily designed for addressing the needs of BIPOC women, BIPOC men were also encouraged to participate because the inclusion of "men of color does not have to mean that other groups are not receiving support and attention" (Hrabowski, 2015, p. 1058). Out of a total of 26 peer mentee participants, a total of four individuals self-identifying as men were enrolled in the program as mentees. Thus, the current paper focuses on the BIPOC men who participated in the online peer mentee training, which encompassed completion of eight online modules, participation in an online Slack community, and attendance at three STEM Webinars. Despite the small number of BIPOC men participating, the current study is significant in that it attends to a persisting gap within the current research literature. The experiences of mentees that identified as women and peer mentors is reported separately (see Wendt & Jones, 2024).

Participants

Prior to recruitment, Institutional Review Board approval was obtained (University of the District of Columbia, IRB Approval # 1414247). In Summer 2020, participants were recruited from two HBCUs (N = 33; n = 7 mentors, n = 26 mentees). Participants were required to be enrolled in a STEM degree program at one of the participating HBCUs, identify as a racial or ethnic minority, and to possess a GPA of 2.0 or higher. After applying, participants were selected by the researchers and an advisory board consisting of STEM faculty and asked to complete the online peer mentee training in Summer 2020 and Fall 2020. During this same period, participants were asked to participate in an online community on the Slack platform. Further, participants were invited to attend three hour-long virtual STEM Webinars, offered in Fall 2020 and Spring 2021, each featuring a talk given by a BIPOC woman who has forged a successful career in a STEM field.

The current paper and related presentation focus on the experiences of one cohort of mentees (n = 4) who self-identified as male and as BIPOC, all of whom were enrolled in undergraduate degree programs (e.g., biology, cybersecurity, computer engineering, and political science) at the same HBCU. This cohort was selected because it was the only cohort that consisted entirely of BIPOC males. The cohort participants identified as Black (n = 2), Arab (n = 1), and Hispanic/Latino (n = 1). It should also be noted that the participating institutions were engaged in emergency remote instruction due to the covid-19 pandemic which, while certainly impacting the participants, did not impact the overall implementation of the program above and beyond extending the amount of time allotted to complete the online training.

Methods

Using a case study design (Merriam, 2009) with the BIPOC male cohort serving as the case, hour-long individual interviews and one hour-long focus group was conducted in Spring 2021 using open-ended questions. Data were then transcribed, and transcriptions were entered into the Delve qualitative analysis program. A combination of inductive and deductive coding was used to code the data within Delve. The use of Delve allowed for simultaneous coding (where the same passage could have more than one code applied to it) and nested coding (where a large passage could include embedded or subcodes) (Saldaña, 2016). The use of deductive coding allowed the researchers to assign codes to passages that attended to the guiding questions and theoretical framework while inductive coding allowed "emergent, data-driven" (Saldaña, 2016, p. 75) codes to be assigned. Using a combination of these approaches, in vivo codes were generated which were then aligned with process codes (Saldaña, 2016). Two rounds of coding were conducted by two different researchers, ensuring agreement and, thus, reliability. Codes were then organized into themes, bringing "meaning and identity to a recurrent [patterned] experience and its variant manifestations" (Saldaña, 2016, p. 199). Overall, five salient themes were identified and agreed upon by the researchers.

When coding data, phrases that attended to the guiding research questions were identified. For instance, the in vivo code 'belonging' was assigned to passages such as "I think that belonging you know like friends, people that looked like me in STEM is what kinda drew me in" (Male 3 Interview)—aligning with the institutional departure model (Tinto, 1987, 1993, 2017) and SCCT (Lent et al., 1994). Simultaneously, the process code 'like others' was assigned to passages such as "It was good to see people that look like me although they were all female" (Male Focus Group)—aligning with identity theory (Chemers et al., 2011; Clark et al., 2016) as well as Tinto's (1987, 1993, 2017) institutional departure model (e.g., integration). Both codes in these examples were then organized into the theme of 'Belonging (I Belong Here)'. As another example, the in vivo code 'identity' was assigned to passages such as "I identify as, you know, Latino" (Male 2 Interview), and the process code 'major' was assigned to passages such as "I'm a political science major" (Male 3 Interview). Both 'identity' and 'major' were combined into the theme of 'Development and Solidification of Identity'. Table 1 provides additional examples of the alignment between the research questions, codes, and themes.

The use of individual interviews and focus groups as multiple methods of data collection served to strengthen the trustworthiness of the data (Merriam, 2009) in tandem with member checking to allow for triangulation. Trustworthiness was further attended to through the process of personal bracketing where researchers used annotation to identify and document biases, seeking to remove personal biases to the furthest extent possible. Dependability was also attended to by memoing which allowed for transparency in decision making (e.g., rationale for coding passages in a certain way; Creswell, 2013).

Findings

Overall, the participants reported overwhelmingly positive experiences in the online peer mentee training and STEM Webinars. Several participants reiterated that they were excited about the training, that the training and STEM Webinars exceeded their expectations, and that they believed that without the training and STEM Webinars, they would not have had similar opportunities to engage in a community of like-minded individuals. Participants noted that "this is an extremely wonderful program…and I'm so grateful that you [the study facilitator] put it together" (Male Focus Group), "everybody wanted to be a part of the program and that made it very, very beneficial" (Male 4 Interview), and "this program is one of the best programs I have ever been in" (Male Focus Group). Participants shared that the incentives to participate in the

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training, including a free laptop and a nominal stipend, were beneficial in supporting their work both within the training and in their academic efforts.

Table 1.

Alignment of Research Questions with Example Codes, Themes, and Passages

Research Question	Code	Theme	Example Passage
RQ1: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' STEM self-efficacy?	Navigating Workforce	Increase in Confidence	They gave me valuable information I feel like I'll be able to use in, like, navigating my career in STEM" (Male 4 Interview)
RQ2: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' sense of community in STEM?	Belonging	Belonging (I Belong Here)	I think that belonging, you know, like friends, people that looked like me in STEM…this is what kind of drew me in" (Male 3 Interview)
RQ3: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' STEM identity?	Identity	Development and Solidification of Identity	"Being able to identify with them just from the online peer mentee my personal identity as a Black man. A Black gay man." (Male 3 Interview)
RQ4: How, if at all, was participation in the online peer mentee training useful in furthering BIPOC male students' intent to persist in a STEM degree program and, ultimately, their intent to pursue a STEM career pathway?	Skills	Persistence and Retention Through Developing Skills	"You know, like you can get all the schooling in the world, but if you don't know how to interact with others… then you end up not being able to hold a job, you know for all long time… I feel like this program can help with that" (Male 3 Interview)
Development of Additional Theme	Inspiring Others	Motivation to Make an Impact	"I'm here to help everybody that needs help" (Male Focus Group).

They also shared that, if given the opportunity, they would participate in the training and STEM Webinars again. One participant shared, "If I had to do it all over again, I would love to do it" (Male 3 Interview). Another participant shared, "If this program will be again, next year, I want to be there" (Male Focus Group). The participants frequently discussed their belief that it is imperative for the training and STEM Webinars to continue, with one sharing "It's very important to keep that, to keep this program going as long as possible" (Male 3 Interview). Participants frequently articulated their beliefs that, if it were not for the current training, they likely would

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not have had an opportunity to gain knowledge and skills about effective peer mentoring relationships and to further reflect on and develop their individual goals. One participant said,

> I feel like I got more out of it than I really would have otherwise, what I think just would have on my own. If that makes sense. I attribute that largely, I think, to just the way that the curriculum was really set up to get us to think about our own goals. Maybe where we see ourselves and the sort of work that we're doing now in service to those goals. (Male 2 Interview)

Further, the data supports that the overall experience in the online peer mentee training and STEM Webinars as a part of the overall online peer mentoring program was powerful in developing the participating BIPOC males' STEM self-efficacy, sense of community, and intent to persist in STEM. Several salient themes were noted, including Development and Solidification of Identity; Increase in Confidence; Motivation to Make an Impact; Belonging (I Belong Here); and Persistence and Retention through Developing Skills.

Development and Solidification of Identity

All the participants reported that their engagement in the peer mentee training and STEM Webinars assisted them in either developing or solidifying their identities. In speaking about the STEM Webinars in particular, one participant said,

> I think it was the very first speaker. I think, as they were sharing their story, you know, and just seeing that the person was, I think, it was a Black woman, you know she was young, and I just, I just, I identify with Black women…. As she was sharing her story, it just, I think that just, that identity…being able to identify with them just from my personal identity as a Black man. A Black gay man. (Male 3 Interview)

Three of the participants reported that their identities as BIPOC individuals were reaffirmed through the STEM Webinars and that they experienced a sort of relief at feeling as if the space within the peer mentoring program and the HBCU community was a supportive and safe space for them to be their unique, whole selves. Male 2 expressed in his interview,

> You know, I identify, as you know, Latino. I'm gay. Uh, you know I'm male. I think there were anxieties about what it would mean, like given the way that, like maybe I physically present, like, you know, would this be, would this be treated, would I be treated differently…?

Another participant summarized the consensus of the participants and their appreciation of the emphasis of the peer mentoring experience on respecting and recognizing diverse identities by sharing,

> I like sort of being recognized as a whole person, right? Like, we're all complex, full people, but going through this program, I feel like there was such an emphasis on

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> diversity, that I can't imagine what this program would have been, if it would have been successful for me, if it was just a 'general people in STEM' feel. (Male Focus Group)

When considering participants' STEM identities, one participant shared several times that he did not at first identify as a STEM student, despite being enrolled in a STEM degree program (political science),

> It [the experience] helped me narrow down to, you know, political science is actually a part of the STEM community—so now I definitely identify as a member of the STEM community. So now I started to seek out, you know, like, STEM programs and, you know, different, like when I'm doing job searches and things. (Male 3 Interview)

Another participant echoed that his experience in the peer mentoring training helped him solidify a STEM identity,

> This program helped me solidify that trajectory…. I had a science background. I didn't know that. It was really an entry point for me for STEM, and so I started doing more IT [information technology] work. And, then, kind of through that discovered, like, cyber security…. Yes, the program really helped me get a better sense of, like, okay, like what I am here. (Male Focus Group)

In the focus group, one participant shared "I'm 100% or maybe 1000% sure about the STEM program". Participants' development and solidification of their personal identities, including a STEM identity, in turn, led to an increase in confidence and, thus, development of STEM self-efficacy.

Increase in Confidence

All participants agreed that their experience in the training led to an increase in their level of confidence in engaging in STEM and navigating the STEM landscape, especially as BIPOC males and, for some, members of the LGBTQ community. When reflecting on his experience, one participant shared, "I don't know that I would have, I would have found that confidence if I wasn't in a space where, like, I was able to talk about my race or my background as openly and honestly" (Male Focus Group). Another participant shared how his confidence in navigating the STEM landscape was increased through the STEM Webinars,

> They were really die-hard activists [the STEM Webinar speakers] …. So, I really, I appreciated them—their experiences and how, particularly, more importantly…how they chose to navigate their particular careers in the workplace, which I feel like I'll definitely be able to use and, like—like, they gave me valuable information I feel like I'll be able to use in, like, navigating my career in STEM. (Male 4 Interview).

Male 2 indicated in his interview that the training and STEM Webinars shaped his confidence in his identities and in belonging in STEM, which would in turn alter his confidence in navigating

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the STEM landscape, sharing, "the sort of way that I navigate the world may be different"—thus demonstrating the impact that participation had on his STEM self-efficacy and sense of belonging. Several times participants discussed the value of the HBCU setting within which the training was situated in increasing their confidence, especially through appreciation of the opportunities to openly discuss their various identities,

> Being at an HBCU, when it comes to sort of like intersectional identity. I still have the impression that, like, race at the end of the day is kind of like the primary concern. So, when it comes to, like, meeting other, like, mentees, who, you know, are sort of also navigating these fields. I feel like the sense of, like, uplift is largely based in, in race, right? Like, we want to see other people who look like us being successful and making money and getting in positions of power. Right? (Male 2 Interview)

All participants indicated that their confidence to engage in "tricky space[s] to navigate" (Male 4 Interview) was increased. This also led to them reflecting on the types of challenges they might encounter in the STEM workforce and the need to diversify STEM--"STEM needs to diversify…it's largely White" (Male 2 Interview).

Motivation to Make an Impact

Each of the participants shared a desire to make an impact, which was influenced by their participation in the training. This was apparent through their individual interviews, but also during the focus group where, at one point, the group began to share resources and opportunities from a local professional organization with each other and to engage in networking. During this moment, one participant shared,

> I'm like this open book that I can help anybody…because I believe one thing. I believe that we are human beings…. We are one person, that we have, like—it's like one body that we have to function together in order to survive. (Male Focus Group)

Another participant echoed, "I'm here to help everybody that needs help" (Male Focus Group), while another shared, "I want to improve myself, to give back to society" (Male Focus Group).

Two participants indicated their desire to mentor someone in the future. One shared that, "I hope, like, in the future, I might be able to do something like this for somebody else" (Male 2 Interview). Another participant stated, "Now I can see myself, I can be a mentor, because I have this experience" (Male 1 Interview). In discussing future mentoring relationships, the participants also shared the importance of a reciprocal relationship so that both mentor and mentee can benefit and have an impact on the other. During the focus group, one participant affirmed, "It's supposed to be mutually beneficial. You know, mentor-mentee relationship, it's supposed to be, like, symbiotic".

One participant shared on several occasions that he felt a personal responsibility to give back and make an impact based on his experience in the program, "I want to be that person that

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does positive, like, around people, like to give them this light" (Male 1 Interview). He shared that he felt a deep appreciation for the opportunity to engage in personal learning and growth, and that his appreciation in turn meant that he had on obligation to reciprocate, "I'm responsible for myself and for community, for other people around me." (Male 1 Interview). Participants, thus, appeared to experience an enhanced sense of altruistic purpose because of participation in the program, which further supported their intent to persist in their respective STEM degree programs and future STEM careers.

Belonging (I Belong Here)

All the participants shared that their experience in the peer mentoring training and participation in the STEM Webinars supported and encouraged their development of a sense of belonging. The STEM Webinars appeared to be especially instrumental in developing a sense of belonging. Participants shared that they appreciated seeing 'like others' in STEM careers and roles. One participant noted, "I think that belonging, you know, like friends, people that looked like me in STEM…this is what kind of drew me in" (Male 3 Interview). This same participant continued, when describing the benefits of the STEM Webinars, "That's what gave me the sense of belonging, because I could identify with each of their [the STEM Webinar speakers'] stories. I kinda identified how it relates to where I am or what my journey may be or where I want to go." While the STEM Webinars featured women, each of the male participants shared that they could identify with the experiences that these women had in their journeys to a STEM career, including their experiences with stereotypes and microaggressions. Another participant shared,

> Hearing from people who, like, look like you or who have experienced some of the similar things as you…Telling you that, like, what you want from your life is valid like, you are deserving of a place at whatever table like, you know, you have in mind like that. That's so important to hear. (Male Focus Group)

Male 3 reaffirmed in his interview, "I think seeing they were primarily Black women…any minority can struggle, you know…telling their struggle makes things feel like it's not just you." Participants concurred that seeing others who had experienced success despite myriad challenges was encouraging and, importantly, assisted them in recognizing that their journeys, while each individually unique, were not journeys that they were taking in isolation—that, in fact, they were not alone. This enabled them to develop a stronger sense of belonging, both within their HBCU and within their respective STEM degree programs.

One participant also shared how his overall experience in the peer mentoring program assisted in his development of a sense of belonging through creation of friendships that may have otherwise not been possible, "I've made friends from this program that I never thought I would make, that I never made in class" (Male 2 Interview). These friendships assisted him in not only building his social network, but also in feeling that he was in a space that was welcoming—a

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space in which he belonged. Male 1 indicated, when reflecting on his first interaction with one of the study facilitators, "I remember the first meeting when I came to pick up the computer and [the facilitator] told me that [she had] a biology background, when I told [her] I'm a biology major…So it says here, and she's a doctor, and she's talking like normal, normal because [she was] like an example, and that's exactly what we need". Throughout each aspect of the program, the participants indicated that they felt welcomed, encouraged, and perceived that the space they occupied was a space in which they belonged.

Persistence and Retention Through Developing Skills

Several times in the individual interviews and the focus groups, participants reflected on skills that they learned through the peer mentee training and STEM Webinars that they perceived as critical to their future success in STEM careers and, thus, furthered their beliefs that they could and should persist in their STEM trajectories. Male 3 indicated in his interview,

> I just think that the program…like these are very important skills, because we do have, there is a, there's a soft skill gap. There's a soft skills gap, you know, amongst the workforce now, and I think programs like this are vital to being able to bridge or help bridge that gap.

This same participant continued,

> You know, like you can get all the schooling in the world, but if you don't know how to interact with others…then you end up not being able to hold a job, you know, for a long time…. I feel like this program can help with that, and so I think that it's vital especially going into the STEM community. (Male 3 Interview)

Another participant shared,

> The program really helped me kind of think about the sorts of important questions and issues that I would want to maybe ask a hiring manager, or maybe as I'm networking on LinkedIn asking a current employee to just have an honest conversation. Like, you know, is diversity sort of like an issue? Is it a value there? (Male 2 Interview)

In addition to the development of soft skills, such as communication skills and questioning skills, participants mentioned that the reflective components of the peer mentee training were beneficial in developing skills for STEM persistence and retention. One participant likened the training to a foundation, "I think without this program as, like, a foundation, I really wouldn't have thought that out on my own. I don't think I would have known" (Male Focus Group). Another appreciated the opportunity to reflect on future goals and engage in goal setting, sharing, "this program really got me to examine, what do I want from, like, a future program?" (Male 2 Interview). This same participant continued "I think with this program, it was the first time that I feel like I actually had—had to kind of plan out what my next steps were." In engaging in reflection, goal setting, and planning, participants further strengthened their resolve to continue in STEM degree programs and careers. This also further supported their development of a STEM identity, their sense of belonging, their perceptions of self-efficacy.

Recommendations for Future Implementation of the Program

While not identified as a theme, participants also shared several suggestions for the training. All participants indicated that, while they appreciated the online nature of the training—especially given that program implementation occurred during a shift to emergency remote instruction at the participating institution due to the covid-19 pandemic—they desired more face-to-face interaction. In fact, several participants shared that they felt that they missed out on potential support and collaboration with each other during the training since they had not had the opportunity to meet in a face-to-face setting. These participants expressed a desire to meet and to serve as a source of encouragement for each other once the pandemic subsides. To address these concerns as this program evolves, although online, regularly scheduled meetings between mentees and mentors should be arranged. Elements such as a social gathering or meet-up can be implemented to attend to the face-to-face needs reported by participants.

Participants in the current study also suggested that a more flexible platform be utilized for cross-cohort communication in subsequent iterations of the program other than the Slack platform. The participants indicated a desire for a more interactive communication platform. Overall, while the Slack platform allowed for communication, it was not perceived by participants as overly effective or easy to use.

Discussion

The current study adds to the body of literature by examining the experiences of BIPOC men as they engaged in online peer mentee training, intentionally engaged in reflection and action directly related to a STEM career path and gained experience in navigating resources—both human and otherwise—related to STEM. The study attends to Gasman and colleagues' (2017) call to action—

> ameliorating the bleak prospects for Black males interested in STEM degrees and the shortage of STEM graduates across the nation rests in no small measure on understanding what educational experiences provide openings to Black male achievement in STEM and how these openings address the gaps in STEM education and, ultimately, the workforce. (p. 182)

While not all individuals within the male cohort identified necessarily as Black, they all identified as BIPOC and reported similar experiences related to the challenges of navigating STEM fields as individuals of color.

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When considering the research questions, the current study demonstrated that the peer mentee training was indeed useful in furthering students' STEM self-efficacy, sense of community in STEM, STEM identity, and intent to persist in a STEM degree program and career among this sample population of BIPOC male students. The study also showed that the peer mentee training can support BIPOC males at one HBCU in identifying mentors, engaging in collaborative relationships with like others, degree and career planning, development of soft skills, and finding opportunities for career advancement. These findings support Tinto's (1987, 1993, 2017) institutional departure model, which demonstrates that both academic and social integration are necessary components for ensuring engagement, skills development, and retention in STEM.

The current study demonstrates the desire for interactions with like others, highlighted by participants' statements about how they identified with the BIPOC women providing the STEM Webinars, so that BIPOC males can see and engage with individuals that have experienced success even when presented with struggles similar to their own. This finding is supported by previous study which reiterated "a widely shared consensus that peer interactions affect student engagement and progress" (Gasman et al., 2017, p. 189), especially related to BIPOC male achievement in STEM. Burt and colleagues (2019), for instance, found that having a "physical example of success" (p. 62) was most important for supporting Black men in persisting in their STEM degree programs. Interactions with like others can facilitate a sense of belonging, improving students' understanding of their 'in group' as it pertains to STEM performance and encouraging enrollment in STEM and persistence in STEM (Walton et al., 2015; Murphy et.al., 2020).

Related to gender-STEM identity, the participants in the current study stated multiple times the benefit of feeling as if they were in a safe and welcoming space that embraced their intersecting identities. Two participants noted that they identified not only as BIPOC men, but also as gay. Their comparison of previous experiences to their current experiences indicated that the openly diverse and welcoming environment of the program, including the representation of diverse individuals within the peer mentee training, supported their development of identity as BIPOC gay men. In fact, they shared that they felt a close identification with the BIPOC women portrayed in the mentee training modules as well as the women featured as speakers for the STEM Webinars as gay individuals. This is significant because, if institutions are to fully support the participation and persistence of BIPOC men in STEM programs, they must also consider how to support those who identify as gender diverse (Sibley & Crane-Seeber, 2020). While it is recognized that those who identify as gender diverse experience increased barriers to STEM participation and success (Hughes, 2018; Sibley & Crane-Seeber, 2020; Stout & Wright, 2016), more research is needed to determine what factors and supports are most influential for men

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identifying as such within STEM. The current findings also reiterate the impact of mentoring on the development of identity, including STEM identity (Atkins et al., 2020; Jehangir et al., 2022).

The findings of the current study echo previous research that reiterated the importance of connection to a higher purpose—characterized as spirituality and religion—to BIPOC men's persistence in STEM (Burt et al., 2019). In the present study, one mentee frequently referenced that "we are one person…one body", drawing on his spirituality and perceptions of being called to a higher purpose. This obligation to contribute to society for mutual benefit in a meaningful way clearly acted as a driving force for his motivation and intent to persist no matter the obstacles faced. Overall, the benefit of the online peer mentee training was solidified, with participants sharing how their participation in the training enhanced their confidence, sense of belonging, and skills development. These findings are in alignment with the literature supporting the need for training for both mentors and mentees, especially in relation to efforts to broaden participation in STEM among minoritized populations (Deanna et al., 2022; Rockinson-Szapkiw et al., 2020). Importantly, the current study adds to the body of literature that, to date, has not yet explored the impact of participation in online peer mentoring programs on BIPOC men enrolled in STEM degree programs at HBCUs.

Recommendations for Future Research

While the population size for the cohort examined in the current study was small, lessons can be gleaned that can inform future mentoring efforts. One future recommendation for research is to implement an online peer mentoring training program that includes a larger sample population of BIPOC males or, perhaps, is dedicated exclusively to BIPOC males to enhance richness of data and to determine generalizability of the current findings. It is also recommended that the population for program recruitment be widened to include a larger number of HBCUs to determine the extent to which the current findings can be generalized to other geographic locations and contexts. By conducting research at several HBCUs, this will allow cross-comparison that could strengthen the themes of the current research, as well as give rise to new themes, to further inform the research in this field. Longitudinal study would also provide insight into the impact of the current online peer mentoring program.

Future implementation of the online peer mentoring program could also include STEM Webinars where BIPOC men were highlighted as featured speakers. Importantly, given challenges related to the Covid-19 pandemic, the current cohort of BIPOC men were only able to complete the online peer mentoring training phase of the project. Future research should examine the impact of engagement in mentoring relationships after the training among BIPOC men. Importantly, while the online peer mentoring program was designed prior to the covid-19 pandemic and was intentionally created to be conducted online, the pandemic prevented participants from electing to meet in the face-to-face environment. Given the isolating nature of the pandemic and the participating institution adopting a posture of emergency remote instruction, future study should explore whether any differences are noted among the online peer mentoring experience outside of the pandemic with restrictions on face-to-face contact lifted. Future implementation might utilize enhanced methods for cross-cohort communication as well, (e.g., other than the Slack platform) and consider a hybrid structure that allowed for the option to engage in face-to-face interaction among program participants.

It should also be noted that the participants in this case study were representative of multiple identities, including gender identities. As such, future study could explore more fully the impact of diverse identities by purposefully recruiting participants with varied gender identities. This would also further attend to a disparity in representation within the research literature (Sibley & Crane-Seeber, 2020).

Conclusion

This study makes a vital contribution to diversifying STEM and addressing inequities by examining the impact of intentional online training for BIPOC male students in STEM programs at HBCUs. While being one of only a few studies that explore male students' experiences at HBCUs, it adds specifically to the limited but growing body of knowledge on online peer mentoring interventions designed to broaden participation in STEM. It is imperative that, given the projected needs for a diverse workforce, institutions explore methods to determine ways in which participation within STEM can be broadened and, most importantly, become more representative of the diverse U.S. population at large, lending itself to creating an inclusive environment. This study demonstrates that the online peer mentee training is beneficial in assisting HBCUs in supporting BIPOC male students' STEM self-efficacy, sense of belonging, STEM identity, and intent to persist in STEM among the sample population studied. Importantly, this study also attends to the need to support students who are not only racially minoritized, but also those with diverse identities as they navigate STEM fields. The study also brings attention to the importance of providing support that broadens participation in STEM, which will allow students of varied experiences and demographic populations to persist and excel in STEM fields. In return, STEM fields may in the future become representative of the population—one that showcases the full spectrum of talent within U.S. society.

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