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REVISTA DE MEDIOS Y EDUCACIÓN
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Assessing Attitudes Toward Science, Technology, Engineering, and Mathematics (STEM) for Enhancing Creativity in Secondary Education

Evaluación de actitudes hacia la ciencia, tecnología, ingeniería y matemáticas (STEM) para fomentar la creatividad en la Educación Secundaria

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ABSTRACT
Students' attitudes towards subjects such as science, technology, engineering, and mathematics (STEM) play a crucial role in the 21st-century learning process. Increasing the number of students pursuing careers in STEM has been widely recognized as important. Consequently, enhancing students' learning and engagement in STEM subjects, as well as fostering positive attitudes toward STEM, has become a primary objective for K-12 STEM education. However, measuring such attitudes in a learning context remains a significant challenge. This research aimed to develop a comprehensive and valid assessment tool to evaluate students' attitudes toward STEM in a learning context for enhancing students creativity. The sample for this research consisted of 311 secondary school students aged 12.83 ± 1.04 years. The validity of the four-factor structure of the model was evaluated using confirmatory factor analysis. Reliability values for the four factors ranged between .73 and .94 with Cronbach Alpha, while those for composite reliability ranged between .97 and .97. The relationship between variables in attitudes toward the STEM instrument identified various path coefficients and effect sizes, indicating strong correlations between the STEM attitude variables. The analysis revealed significant differences according to grade level, with grade 9 students showing better or at least competitive performance in most disciplines. This questionnaire was found to be a feasible instrument to assess secondary school students' STEM attitudes. These findings have important implications for STEM education strategies, emphasizing the need for sustained and focused approaches to deep learning experiences for all students, regardless of gender.

RESUMEN
Las actitudes de los estudiantes hacia asignaturas como ciencia, tecnología, ingeniería y matemáticas (STEM) desempeñan un papel crucial en el proceso de aprendizaje del siglo XXI. Aumentar el número de estudiantes que eligen carreras en STEM se ha reconocido como importante. En consecuencia, mejorar el aprendizaje y la participación de los estudiantes en las asignaturas STEM, así como fomentar actitudes positivas hacia STEM, se ha convertido en un objetivo principal para la educación STEM en K-12. Sin embargo, medir tales actitudes en un contexto de aprendizaje sigue siendo un desafío significativo. Esta investigación ha tenido como objetivo desarrollar una herramienta de evaluación completa y válida para evaluar las actitudes de los estudiantes hacia STEM en un contexto de aprendizaje, con el fin de mejorar su creatividad. La muestra para esta investigación ha consistido en 311 estudiantes de secundaria con una media de edad de 12,83 ± 1,04 años. La validez de la estructura de cuatro factores del modelo ha sido evaluada utilizando un análisis factorial confirmatorio. Los valores de fiabilidad para los cuatro factores han oscilado entre .73 y .94 con Alfa de Cronbach, mientras que los de fiabilidad compuesta han oscilado entre .97 y .97. La relación entre las variables en las actitudes hacia el instrumento STEM ha identificado varios coeficientes de ruta y tamaños de efecto, indicando fuertes correlaciones entre las variables de actitud STEM. El análisis ha revelado diferencias significativas según el nivel de grado, mostrando que los estudiantes de noveno grado han presentado un rendimiento mejor o al menos competitivo en la mayoría de las disciplinas. Se ha encontrado que este cuestionario es un instrumento viable para evaluar las actitudes STEM de los estudiantes de secundaria. Estos hallazgos tienen importantes implicaciones para las estrategias de educación STEM, enfatizando la necesidad de enfoques sostenidos y enfocados en experiencias de aprendizaje profundo para todos los estudiantes, independientemente del género.

KEYWORDS · PALABRAS CLAVES
Actitudes estudiantiles; Creatividad; Educación secundaria; Evaluación de actitudes; Educación STEM; Autoeficacia; Análisis factorial confirmatorio; Student attitudes; Creativity; Secondary education; Attitude assessment; STEM education; Self-efficacy; Confirmatory factor analysis

1. Introduction

Students' attitudes towards subjects such as science, engineering, and mathematics (STEM) play an important role in the 21st century learning process. The importance of increasing the number of Indonesian students pursuing careers in STEM has been widely recognised and documented (Rusmana et al., 2021). Employment projections for occupation groups from 2020 to 2030 indicate significant growth in several STEM fields. Data scientists and mathematical science occupations are expected to increase by 31.4%, statisticians by 35.4%, and physical therapist assistants by 35.4%. In engineering, solar photovoltaic installers are projected to grow by 52.1%, and wind turbine service technicians by 68.2% (Dubina et al., 2021). Therefore, enhancing students' learning and engagement in STEM subjects, as well as fostering positive attitudes toward STEM, has become a primary objective for K-12 STEM education in Indonesia.

Creativity is also a crucial component of STEM education, as it encourages innovative thinking and problem-solving skills essential for tackling real-world challenges (Siew & Ambo, 2018). Previous research has shown that positive attitudes towards these subjects can increase learning motivation, student engagement in the learning process, and overall academic achievement (Sölpük, 2017). Moreover, incorporating design thinking into STEM education has enhanced children's creativity and problem-solving abilities (Yalçın & Erden, 2021). However, measuring such attitudes in a learning context remains a significant challenge. Therefore, it is important to develop effective assessment tools to assess students' attitudes towards STEM to make the classroom learning process more efficient and effective.

The development of an attitude towards STEM instrument is important as it allows for a more holistic evaluation of students' attitudes towards science, technology, engineering, and mathematics. With a good evaluation tool in place, educators can understand students' preferences, inclinations, and perceptions toward these subjects. In addition, the development of an instrument for attitudes towards STEM is important to track changes in students' attitudes over time. This allows for measuring the effectiveness of learning programmes that focus on STEM concepts.

Previous research has highlighted various aspects of students' attitudes towards STEM. Some of these aspects include interest in learning, self-confidence, perceived value of the subject, as well as the desire to be active in learning (Edwards et al., 2023; Kong & Mohd Matore, 2022; Macun & Cemalettin, 2022; Temel, 2023). It is important to be able to measure exactly these aspects when designing a comprehensive assessment tool. In addition, an effective assessment tool should also be able to provide valuable information to educators in understanding the level of student attitudes toward the subject. Previous research emphasises that these types of assessment tools should provide measurable, valid and reliable information for teachers in adjusting their teaching methods (Guàrdia et al., 2023).

However, designing an assessment tool to measure students' attitudes towards STEM is not an easy task. Recently, various instruments have been created to measure student attitudes toward the four STEM fields collectively. However, these instruments lack items that address integrated STEM education, which emphasises the fusion of all four subject areas (e.g., (Antonietti et al., 2023; Benek & Akcay, 2019; Wahono & Chang, 2019; Wicaksono & Korom, 2023)). For example, Antonietti et al. (2023) developed the ICAP Technology scale to measure how technology is integrated into learning activities in the

German context. The results showed that the four developed scales were reliable, valid, and had a positive relationship on each scale. Furthermore, Wicaksono & Korom (2023) developed an instrument to measure attitudes toward science with a sample of students in higher education. The results showed that the instrument has good psychometric properties and can be relied upon, the value of good fit based on the Rasch model can also be relied upon. Although the study was in the context of Indonesia, the sample was in the context of higher education. Research provides insight into the development of evaluation measurement tools, but is limited to the scope of the sample, such as elementary schools, higher education, and western contexts. This provides a good opportunity to develop STEM evaluation tools in the context of secondary school students.

Therefore, this research aims to develop a comprehensive and valid assessment tool to evaluate students' attitudes toward STEM in a learning context on enhancing students creativity. The research addresses the following questions:

- Are the instruments to measure attitudes toward STEM reliable and valid?
- What is the relationship between variables in attitudes toward the STEM instrument?
- Are there differences in students' attitudes toward STEM based on sample backgrounds, such as gender and grade?

1.1.STEM education

The development of the STEM attitude questionnaire is based on learning theory and cognitive psychology, involving the concept of self-efficacy, as explained by Bandura (1969). The theory of self-efficacy posits that an individual's belief in their own abilities influences their behaviour, motivation, and achievement. In the context of attitudes toward STEM, self-efficacy plays a crucial role in shaping students' perceptions of their ability to master STEM subjects (Luo et al., 2021). When developing the STEM attitude instrument, the concept of self-efficacy becomes relevant because it affects how confident students feel about tackling STEM lessons (DeCoito & Myszkal, 2018). Students with high self-efficacy in STEM tend to have more positive attitudes towards these subjects (Blotnicky et al., 2018), feel more capable of mastering the material (Cervone et al., 2020), and are more motivated to learn (Kryshko et al., 2022). Building upon the foundational concept of self-efficacy in STEM attitude assessment, it's crucial to recognize its multifaceted nature and far-reaching implications. Self-efficacy in STEM is often domain-specific, varying across disciplines (Thompson et al., 2024) and significantly influencing students' career aspirations (Rosenzweig & Chen, 2023). It intersects with important factors such as gender, diversity, and cultural background (Ogodo, 2023; Sparks et al., 2023), necessitating a nuanced approach in questionnaire design. The concept is closely tied to growth mindset, persistence, and resilience in STEM learning (Höhne et al., 2024), as well as being shaped by past experiences and social support systems (Akiri & Dori, 2022).

Bandura (1997) theory of self-efficacy, also provides insight into how students' perceptions of success and failure in the context of STEM can shape their attitudes toward these subjects (Van Aalderen-Smeets & Walma Van Der Molen, 2018). If students feel capable of overcoming difficulties and challenges in STEM learning (Wilson, 2021), they are likely to have a more positive attitude toward these subjects (X. Wang, 2013). These theories view attitudes as mental constructs that influence an individual's perception and behaviour. The theoretical foundation includes learning concepts that emphasise the interaction between environmental factors and personality in shaping one's attitude toward STEM.

Students' attitudes toward STEM are a primary focus in the development of this assessment tool. According to research by Osborne dkk. (2003), attitudes encompass aspects such as positive or negative feelings toward STEM, perceived value of STEM, and interest in activities related to this field. Their research shows that a positive attitude toward STEM is closely related to intrinsic motivation in learning and student participation in the learning process.

Many studies link positive attitudes toward STEM with academic success and career interest in science and technology fields (Durakovic, 2022; Göktepe Körpeoğlu & Göktepe Yıldız, 2023; Óturai et al., 2023). The STEM attitude questionnaire allows for the identification of key variables that influence students' interest in these sciences. It also helps researchers develop more effective and engaging learning strategies for students. Additionally, the STEM attitude questionnaire is an important instrument to evaluate the effectiveness of STEM curricula. By obtaining information about students' attitudes toward these subjects, educators can adjust teaching methods and curriculum content to be more relevant and engaging for students.

Previous research shows that students with positive attitudes towards STEM tend to have a higher interest in pursuing careers in these fields (Chiu & Li, 2023; Ozulku & Kloser, 2023; Xu & Lastrapes, 2022), motivation (Dökme et al., 2022), emotional (Koul et al., 2023). Therefore, the STEM attitude questionnaire helps identify factors that encourage students' interest in continuing their education in STEM fields at higher levels.

1.2. STEM innovation in secondary education

STEM learning at the secondary education level requires a holistic and integrated approach to teaching STEM concepts to students (English, 2016). According to Asigigan & Samur (2021), an effective STEM learning approach should promote problem solving, critical thinking, and the application of theoretical concepts in real world contexts. This helps develop students' skills in creative thinking (Suherman & Vidákovich, 2024), collaboration (Chen et al., 2019), and solving complex problems (Tan et al., 2023), all of which contribute to positive attitudes toward STEM (Steinberg & Diekman, 2017). Furthermore, the evaluation of STEM learning at the secondary education level requires effective tools that can assess students' comprehension and application of STEM concepts (Saxton et al., 2014). These tools should not only measure academic achievement but also gauge students' abilities to innovate, analyse data, and apply scientific principles in practical settings. Such assessments are crucial for ensuring that students are prepared to meet the challenges of today's technological and scientific advancements.

Motivation to learn is a crucial factor in measuring student responses to STEM education. According to Eccles & Wigfield (2002), learning motivation encompasses students' intrinsic and extrinsic desires to achieve academic goals and personal development in the context of STEM learning. Intrinsic motivation is closely related to students' interest in STEM fields, whereas extrinsic motivation can be influenced by external factors such as rewards or praise from others. Incorporating motivational strategies in STEM education can foster a more positive attitude among students towards these subjects. Additionally, the integration of STEM disciplines, supported by technology and mathematics, can enhance student achievement across all scientific fields (Farida et al., 2024; Komarudin & Suherman, 2024; Nguyen et al., 2020).

Recent research has highlighted the importance of technological integration and innovative pedagogical approaches in enhancing STEM education at the secondary level. The use of augmented reality (AR) and virtual reality (VR) technologies in STEM classrooms has shown promising results in increasing student engagement and conceptual understanding (T. Lee et al., 2022). Moreover, project-based learning (PBL) approaches in STEM education have been found to significantly improve students' problem-solving skills and attitudes towards STEM subjects (AlAli, 2024). The incorporation of computational thinking into STEM curricula has also gained traction, with studies showing its positive impact on students' analytical skills and future-ready competencies (H.-Y. Lee et al., 2023). Additionally, the development of STEM identity among secondary school students has been identified as a crucial factor in their long-term engagement with STEM fields, emphasizing the need for culturally responsive STEM education that resonates with diverse student populations (Xie & Ferguson, 2024).

1.3. Assessment Tools for Measuring STEM

Over the past five decades, the development of measurement tools to evaluate STEM education has evolved significantly (Okulu & Oguz-Unver, 2021). The need to assess various aspects of STEM education has led to the creation of numerous assessment tools, each aiming to measure different dimensions such as knowledge, skills, attitudes, and self-efficacy among students.

The early efforts to develop STEM assessment tools focused primarily on evaluating the outcomes of cognitive learning. Traditional tests and quizzes were the primary methods used to measure students' understanding of scientific concepts and principles. During the 1970s and 1980s, standardised tests such as the SAT and ACT included sections to assess mathematical and scientific reasoning, providing a broad but limited measure of STEM education outcomes (Clarke et al., 2000). In the late twentieth and early twentieth centuries, the focus shifted towards creating more integrated and comprehensive assessment tools that could evaluate multiple dimensions of STEM education simultaneously. Instruments such as the Student Attitudes toward STEM Survey (S-STEM) (Unfried et al., 2015), and the STEM Semantics Survey (Knezek & Christensen, 2008) were developed to provide a more holistic view of students' experiences and attitudes toward STEM subjects. The S-STEM survey, developed by Unfried et al. (2015), included scales for science, technology, engineering, and mathematics, as well as skills for the 21st century. This tool was designed to measure students' self-efficacy, interest, and perceived value of STEM subjects. The STEM Semantics Survey (Knezek & Christensen, 2008) also sought to assess students' attitudes toward STEM by assessing their feelings and beliefs about the subjects. Furthermore, research conducted by Suprapto (2016) focused on developing attitudes toward STEM. However, these instruments were specifically designed to measure attitudes toward individual STEM fields.

Research by Wan et al. (2022) developed and validated a multi-dimensional scale to measure students' experiences in STEM project-based learning (PBL). The scale includes four key dimensions: engagement in learning, collaboration, creativity, and real-world relevance, with strong reliability and validity (Cronbach’s alpha .75 to .89). While the scale is a valuable tool for assessing STEM PBL, its limitations include a narrow sample size and geographic scope, potentially affecting generalizability. It also doesn't account for external factors like teacher support or curriculum variations, suggesting a need for broader studies to address these gaps. At the same time Wicaksono & Korom (2023) developed and validated a questionnaire to assess attitudes towards science among science teacher candidates and engineering students in Indonesia. The questionnaire focused on dimensions such as interest in science, perceived relevance, and self-efficacy, showing high internal consistency (Cronbach's alpha .80 to .92). However, the study's limitations include a focus on specific science student populations in Indonesia, which may limit its applicability to other contexts or fields. Additionally, other subjects (i.e., math, engineering, technology) that could influence attitudes toward student were not fully explored, indicating a need for further research. In other words, S.-P. Tsai et al. (2023) created and initially validated a scale aimed at assessing middle school students' attitudes toward STEM learning. Results demonstrated strong internal consistency and confirmed the four-factor structure through factor analysis. However, limitations include the narrow focus on a specific group of middle school students, potentially limiting the generalizability of the results. Additional research and validation in diverse cultural settings and age groups are needed to expand its use.

Additionally, the integration of advanced psychometric techniques and statistical methods has improved the reliability and validity of STEM assessment tools. Item response theory (IRT) and factor analysis are commonly used to refine and validate these instruments, ensuring that they accurately measure the intended constructs. Given the limitations of existing STEM attitude measurement tools, particularly in terms of generalizability and applicability across different cultural and educational contexts, there is a clear need for instruments specifically designed for the Indonesian context. Additionally, considering the importance of addressing local educational needs and the evolving STEM landscape, developing a contextually relevant assessment tool would provide educators and policymakers with valuable insights to enhance STEM engagement and outcomes in Indonesia.

2. Methodhology

2.1. Participants

The sample for this research consisted of 311 secondary school students aged 11 to 14 years (M_{age} = 12.83; *SD* = 1.04). Most of the participants were women (80.1%). The students were randomly selected from 19 different secondary schools in Bandar Lampung, Indonesia, and completed an online questionnaire that took an average of 15 minutes to complete. The study was approved by the Institutional Review Board of Universitas Negeri Raden Intan

Lampung, Indonesia, adhering to the ethical guidelines set by the institution. Detailed demographic information about the participants is presented in Table 1.

Table 1

The characteristics of the participants

Characteristics	Frequency	Percentage (%)
Gender		
Female	151	48.6
Male	160	51.4
Grade		
7	142	45.7
8	103	33.1
9	66	21.2
School Place		
Public	142	45.7
Private	169	54.3
Living Place		
District	68	21.9
City	165	53.1
Urban	78	25.1

2.1. Instruments

In this investigation, the instruments developed by Unfried et al. (2015) were examined through four scales: science (8 items), technology/engineering (9 items), mathematics (4 items), and skills of the 21st century (11 items). Students were asked to indicate their agreement with each statement using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Additionally, the students provided demographic information including age, gender, grade, school location, and place of residence.

2.2. Procedure

The original questionnaire was initially created in English. Since the students in our sample spoke Indonesian primarily as their native language, with English their second language, it was necessary to translate the questionnaire into Indonesian. This ensured that all participants could understand the content, thus improving the validity of the instrument through accurate translation. The translation was performed by a team consisting of a Ph.D. holder from the UK, a Ph.D. candidate from Ireland, and a Ph.D. candidate from Japan, all of whom had extensive expertise in science, mathematics, engineering, and linguistics. The newly translated versions were meticulously reviewed, compared, and critiqued. Minor adjustments in word choice were made to clarify any ambiguous points. Subsequently, a trial version of the Indonesian questionnaire was emailed to field experts for review. These experts assessed the validity of the questions and the general content, suggesting specific words and phrases to ensure clarity and comprehension.

2.3. Data Analysis

In data analysis, the researchers will employ SPSS version 29, Winstep version 4.0, and R software. SPSS will be used to examine descriptive statistics such as mean, median, and standard deviation, providing an overview of the data distribution. Confirmatory factor analysis (CFA) will be performed to assess the fit of the model within the measurement model (Jomnonkwao & Ratanavaraha, 2016). CFA follows fit indices to evaluate model adequacy, including the Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Goodness-of-Fit Index (GFI), Root Mean Square Error of Approximation (RMSEA), Standardised Root Mean Square Residual (SRMR) and the Kaiser-Meyer-Olkin (KMO) index (Kline, 2015). The cutoff values for each parameter are CFI > 0.90; TLI > 0.90; RMSEA < 0.08; and SRMR < 0.06 (Boone et al., 2014; Hu & Bentler, 1999). Additionally, a principal component analysis was conducted, and items with values lower than .30 were excluded from further consideration. Several items that fell below this threshold were removed from the database. This aligns with the recommended threshold value of .40 suggested by experts in social science research (Straub et al., 2004).

Furthermore, chi-square statistics, including degrees of freedom and p-values, will be mathematically represented. According to Kline (2015), the statistics of the chi-square test are highly sensitive to sample size, with statistically significant chi-square values found more frequently in larger samples. The study will also perform reliability and validity analyses of the instrument. The construct reliability will be assessed using Cronbach's alpha, composite reliability (rho_c), and average variance extracted (AVE). Discriminant validity will be evaluated using the $HTMT_{0.90}$ ratio of correlations among four factors. Furthermore, the R software will be used to analyse the performance of the respondents regarding the STEM attitude instrument, employing pirate plot violine (Phillips, 2017).

3. Results

3.1. CFA

CFA was used to confirm the latent factors in the measurement model, indicating that all the latent factors performed well and achieved the GoF (Goodness of Fit) index. Following the recommendations of Chuah et al. (2016), we conducted an analysis for construct reliability and discriminant validity. To assess the fit of the model, we created a CFA diagram in the measurement model using the pattern matrix builder plugin from Gaskin & Lim (2016). In this structural model, the one-headed arrows indicate the hypothesised one-way direction in the structured model, while the two-headed arrows indicate correlations between two variables in the structured model. Latent variables (e.g., questionnaire factors) are represented by ovals, while observed variables (e.g., questionnaire items) are represented by rectangles. The small circles on the graph represent the measurement errors associated with each observed indicator.

In this study, we found that the loading factors did not meet the threshold criteria (Straub et al., 2004). Therefore, we removed four items with loading factor values below 0.30. These included the statements MA1 ((-) Mathematics is my worst subject), MA3 ((-) Mathematics is difficult for me), MA4 (I am the type of student who performs well in mathematics), and MA5 ((-) I can handle most subjects well, but I cannot do mathematics well). We analyse the report using modification indices and covariances with items in the same factor that had values greater than .30 to achieve outstanding results and improve the fit of the model in the CFA. A more accurate model fit was obtained (χ^2 = 1094.076; χ^2/df = 457; *p* < .001; CFI =0.906; TLI = .898; RMSEA = .067; and SRMR = .055). The CFA diagram and modification indices are shown in Figure 1, and the factor loading values are shown in Table 2.

Table 2

Factor loading of the items

No. Item	Items	21st Century	Technology/ Engineering	Math	Science
SK1	I am confident that I can help others accomplish a goal.	.78			
SK2	I am confident I can encourage others to do their best	.84			
SK3	I am confident I can produce high quality work	.85			
SK4	I am confident I can respect the differences of my peers	.85			
SK5	I am confident I can help my peers	.86			
SK6	I am confident I can include others' perspectives when making decisions	.79			
SK7	I am confident I can make changes when things do not go as planned	.77			
SK8	I am confident I can set my own learning goals	.83			
SK9	I am confident I can manage my time wisely when working on my own	.86			

No. Item	Items	21st Century	Technology/ Engineering	Math	Science
SK10	When I have many assignments, I can choose which ones need to be done first	.82			
SK11	I am confident I can work well with students from different background	.82			
EN1	I like to imagine creating new products		.74		
EN2	If I learn engineering, then I can improve things that people use every day		.74		
EN3	I am good at building and fixing things		.70		
EN4	I am interested in what makes machines work		.60		
EN5	Designing products or structures will be important for my future work		.77		
EN6	I am curious about how electronics work		.72		
EN7	I would like to use creativity and innovation in my future work		.80		
EN8	Knowing how to use math and science together will allow me to invent useful things		.73		
EN9	I believe I can be successful in a career in engineering		.69		
MA2	I would consider choosing a career that uses math			.39	
MA6	I am sure I could do advanced work in math			.70	
MA7	can get good grades in math			.78	
MA8	I am good at math			.56	
SC1	I am sure of myself when I do science				.68
SC2	I would consider a career in science				.69
SC3	I expect to use science when I get out of school				.67

No. Item	Items	21st Century	Technology/ Engineering	Math	Science
SC4	Knowing science will help me earn a living				.69
SC5	I will need science for my future work				.66
	I know I can do well in science				
SC6	Science will be important to me in my life's work				.79
SC7	(-) I can handle most subjects well, but I cannot do a good job with science				.31
SC8	I am sure I could do advanced work in science				.77

3.2. Construct reliability

We utilized construct reliability to assess the internal consistency and convergent validity of the items. The results of the construct reliability are detailed in Table 3.

Table 3

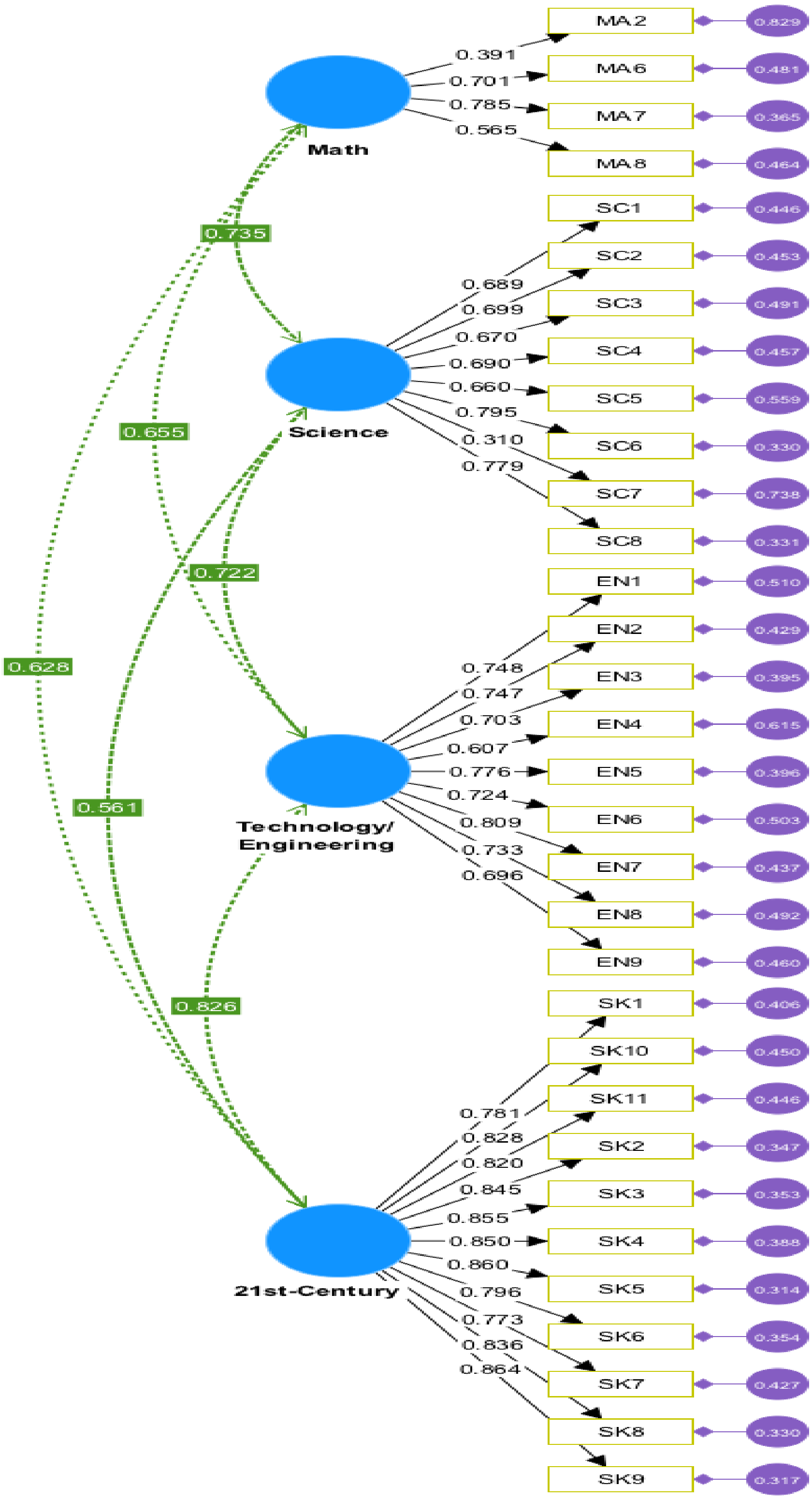
Construct reliability of the scales

	Cronbach's alpha	Composite reliability (rho_c)	(AVE)
21st-Century	.94	.97	.78
Technology/Engineering	.91	.94	.64
Math	.73	.87	.64
Science	.89	.94	.68

Table 3 presents the construction reliability of the measured items using Cronbach's alpha, composite reliability, and AVE across four main domains: 21st century skills, engineering, mathematics, and science. The analysis results indicate that the 21st century skills domain has a Cronbach alpha of .94, a composite reliability of .97, and an AVE of .78. The engineering domain shows a Cronbach alpha of .91, a composite reliability of .94, and an AVE of .64. The mathematics domain has a Cronbach alpha of .73, a composite reliability of .87, and an AVE of .64. Finally, the science domain demonstrates a Cronbach alpha of .89, a composite reliability of .94, and an AVE of .68. Based on these results, it can be concluded that all domains possess adequate construct reliability, with Cronbach's alpha values above .70, indicating good internal consistency, and composite reliability and AVE values that demonstrate sufficient convergent validity for each construct.

Figure 1

Model CFA



3.2. Discriminant Validity

This study used discriminant validity. The discriminant validity test was performed to assess whether the latent factors are distinct from each other at the empirical level, as shown in Table 4.

Table 4

$HTMT_{0.90}$ Ratio of the Four Correlations Factors

	21st Century	Technology/Engineering	Math	Science
21st Century				
Technology/Engineering	.81			
Math	.64	.67		
Science	.57	.73	.79	

In this study, the results in Table 4 indicated acceptable discriminant validity among the factors. The HTMT ratios between 21st century skills and technology / engineering, maths, and science were .81, .64, and .57, respectively. Similarly, Technology/Engineering showed HTMT ratios of .67 with Maths and .73 with Science. Lastly, the HTMT ratio between mathematics and science was .79. These values are below the threshold of .90, demonstrating that each factor is distinct and not highly correlated with the others, thus confirming the discriminant validity of the constructs. This analysis ensures that the measurement model accurately captures the unique aspects of each factor, enhancing the credibility and reliability of the study's findings.

3.3. The relationship between variables in attitudes toward the STEM instrument

The relationships between variables in the STEM attitudes instrument can be seen in Figure 1. The values of the path coefficient (β) between variables vary. The coefficient between attitudes toward mathematics and science is β = 0.735. The coefficients between attitudes toward mathematics and engineering / technology and mathematics and skills of the 21st century are β = 0.655 and β = 0.828, respectively. Furthermore, the coefficient between attitudes toward science and engineering/technology is β = 0.722, and between science and skills of the 21st century is β = 0.561. Lastly, the coefficient between attitudes towards engineering / technology and skills of the 21st century is β = 0.826.

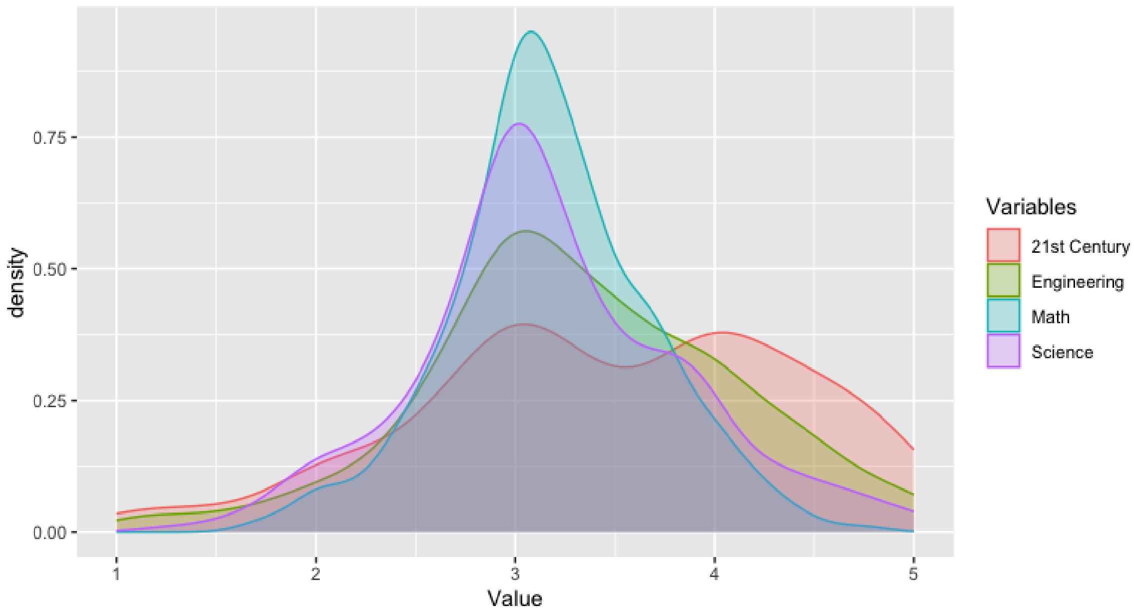
To analyse the scale scores of all components of the STEM attitudes questionnaire, we compared the mean scores of the four latent factors using an independent sample t-test. Effect sizes were also determined according to Cohen's d. The effect size criteria include the following categories: negligible (0-0.19), small (0.2-0.49), medium (0.5-0.79), and large (> 0.8) (Cohen, 1992). This study found that the variables mathematics ($t(309) = 0.408$, $p > 0.05$, Cohen's d = 0.49), science ($t(309) = -0.869$, $p > 0.05$, Cohen's d = 0.66), engineering (t(309) = 0.970, *p* > 0.05, Cohen's d = 0.77), and 21st-century skills (t(309) = 1.026, *p* > 0.05, Cohen's d = 0.93) demonstrated varying degrees of effect sizes.

3.4. Students' differences in attitudes toward STEM due to gender and grade level

This study examined how the students' abilities to complete the STEM attitudes questionnaire varied based on background factors, specifically gender and grade level, as shown in Figure 2.

Figure 2

Pirate plot based on gender and grade for all variables



Regarding gender, we found that Wilks' Lambda was greater than 0.05, indicating that there were no significant differences among the four variables. For the maths variable, men had a mean score of 3.196 with an SD of 0.06, while women had a mean score of 3.16 with an SD of 0.03. In the science variable, men had a mean score of 3.14 with an SD of 0.08, compared to women who had a mean score of 3.18 with an SD of 0.04. For the engineering variable, males had a mean score of 3.35 with an SD of 0.09, while females had a mean score of 3.30 with an SD of 0.04. Lastly, for the skills variable of the 21st century, men had a mean score of 3.57 with an SD of 0.11, while women had a mean score of 3.44 with an SD of 0.05.

In terms of subjects, we found that Wilks' Lambda was 0.492. For the mathematics variable, the *F* value was 11.350,7; *p* < 0.001. For the science variable, the *F* value was 6462,9; *p* < 0.001. The engineering/technology variable had an F value of 5228,6; *p* < 0.001, and the 21st century skills variable had an *F* value of 3968,2; *p* < 0.001.

The study also compared the descriptive statistics for grades 7, 8, and 9 for all observed variables: Mathematics, Science, Technology / Engineering and 21st century skills. For the Mathematics variable, the average score for grade 7 was 3.16 with an SD of 0.46, grade 8 had an average score of 3.20 with an SD of 0.50, and grade 9 had an average score of 3.14 with an SD of 0.54. In the science variable, grade 7 had an average score of 3.14 with an SD of 0.64, grade 8 had an average score of 3.16 with an SD of 0.68, and grade 9 had an average score of 3.287 with an SD of 0.70. For the Technology/Engineering variable, grade 7 had an average score of 3.28 with an SD of 0.78, grade 8 had an average score of 3.31 with an SD of 0.74, and grade 9 had an average score of 3.38 with an SD of 0.79. Lastly, for the 21st century skills variable, grade 7 had an average score of 3.39 with an SD of 0.81, grade 8 had an average score of 3.51 with an SD of 0.95, and grade 9 had an average score of 3.57 with an SD of 0.84.

This analysis indicates variations in mean scores and standard deviations between grades 7, 8, and 9 in each discipline, with differences reflecting consistent patterns or higher variability depending on the discipline. Overall, the analysis suggests that grade 9 students generally performed better or at least compared to most disciplines.

4. Dicussions

This study developed and validated a STEM attitude questionnaire. Research focused on assessing the reliability of statement items through confirmatory factor analysis (CFA). Our goal was to determine whether the statement items could be classified as suitable items based on their conceptual meaning. The results indicated that CFA provided data consistent with the model fit guidelines. However, several statements did not meet the statistical or fit criteria of the CFA model, primarily due to factor loadings below 0.3. For example, on the mathematics attitude scale, four statements were deemed unsuitable based on CFA results. Statements such as "Mathematics is my worst subject" and "Mathematics is difficult for me," which are negatively worded items, showed low factor loadings. This was influenced by the fact that for many students, mathematics is perceived as a challenging subject, leading them to often strongly agree (score 5) with such statements. This study underscores the importance of evaluating the construct of each statement item between meaning and statistical data to achieve more comprehensive results. According to Cheung dkk. (2023), CFA is an effective method for validating theoretical constructs by testing relationships between latent variables and measurable indicators. However, the study also emphasises the critical role of understanding the context of the student and the interpretation of the statement items in assessing the reliability and validity of the evaluation instruments. Therefore, in developing evaluation instruments, a thorough analysis should be performed not only based on statistical data but also considering the meaning and context of each statement. This ensures that the developed instrument accurately measures the intended construction reliably (Farida et al., 2022; Suherman & Vidákovich, 2022).

This study reinforces previous findings on the importance of validation to ensure the reliability and validity of evaluation instruments. According to Kline (2015), high path coefficients indicate significant relationships between latent variables and their indicators, supporting that the theoretical constructs are empirically sound. Furthermore, large effect sizes indicate that STEM attitude variables have significant impacts within this research context. Cohen (1992) states that effect size provides information about the magnitude of the relationship or impact of one variable on another, crucial for interpreting research findings. In this context, effect sizes ranging from .49 to .93 suggest that STEM attitudes substantially contribute to the research model. With positive and strong path coefficient and effect size results, this study confirms that the developed STEM attitude evaluation instrument has good validity and reliability in accurately measuring student attitudes. Therefore, this instrument can be used in further research to evaluate and improve STEM learning in schools.

Furthermore, the study explored how the ability of the student to complete the STEM attitude questionnaire is influenced by background factors, particularly gender and grade level. This analysis aimed to identify differences in STEM attitudes based on these variables, providing crucial information for educators and policymakers in designing more inclusive and effective learning strategies.

The study did not find significant differences based on gender in all observed variables. Mathematics, Science, Engineering/Technology, and 21st Century Skills. Mean values and standard deviations between men and women also indicated a relatively close similarity in each variable. This finding aligns with research by N. Wang et al. (2023), showing that gender differences in attitudes and performance towards STEM often prove insignificant when considering other factors, such as intrinsic motivation and environmental support. Therefore, this study confirms that STEM attitudes among students do not differ significantly between males and females, indicating equal potential in this field. The lack of significant gender differences observed in the current study's variables (Mathematics, Science, Engineering/Technology, and 21st Century Skills) suggests that efforts to promote gender equality in STEM education may be bearing fruit. However, it's important to note that while attitudes and skills may be similar, other factors can still influence career choices and persistence in STEM fields. For instance, Zając et al. (2024) found that despite similar abilities, women were more likely to opt out of certain STEM fields due to perceived lack of work-life balance and concerns about workplace culture. This indicates that addressing systemic issues in STEM industries remains crucial for achieving true gender parity. Moreover, intersectionality plays a vital role in understanding STEM participation. Sendze (2023) demonstrated that women of color face unique challenges in STEM fields, highlighting the need for more nuanced approaches to promoting diversity and inclusion.

The analysis revealed significant differences according to grade level. Mean scores and standard deviations between grades 7, 8, and 9 exhibited intriguing variations in each discipline. Overall, grade 9 showed better or at least competitive performance in most disciplines. This result is consistent with previous findings by Balta et al. (2023), suggesting that STEM attitudes may change with increasing grade levels, where richer learning experiences and deeper engagement in STEM activities can strengthen positive attitudes toward the discipline. Improved performance and more positive attitudes among grade 9 students may reflect increased exposure to and understanding of STEM content over time. As students advance through their educational journey, they encounter more complex concepts and real-world applications that foster critical thinking and problem-solving skills (Supriadi et al., 2024; Tuong et al., 2023).This maturation process not only improves their academic performance but also cultivates a more profound appreciation for the relevance and importance of STEM fields. Furthermore, this trend raises important questions about curriculum design and instructional strategies at lower grade levels. If earlier exposure and engagement in STEM subjects can lead to better attitudes and performance in higher grades, educational stakeholders should consider how to enhance STEM education in grades 7 and 8. Implementing hands-on projects, collaborative learning opportunities, and real-life problem-solving scenarios could help younger students develop a stronger foundation and interest in STEM subjects (Ammar et al., 2024; Huang et al., 2022; Nikolopoulou, 2023).

Although no significant differences were found based on sex, notable differences were observed based on grade level, indicating that longer learning experiences and deeper participation in STEM can improve positive attitudes toward this discipline. These findings have important implications for STEM education strategies, emphasising the need for sustained and focused approaches to deep learning experiences for all students, regardless of gender.

The results indicate a correlation with previous research on the influence of STEM education on students' skills and academic achievements. This suggests that implementing STEM learning and assessment is important in preparing a competent generation that meets the demands of the global era (Abina et al., 2024). Students' attitudes toward STEM play a crucial role in determining their willingness to learn STEM subjects and pursue a career in STEM (Maltese & Tai, 2011).

5. Limitations and future research

This study has several limitations that must be noted. First, the research sample was limited to high school students in Lampung, Indonesia; hence, the results may not be generalizable to the entire student population in Indonesia or other regions. While this research has the potential to assess students' attitudes toward STEM on a global scale, it is crucial to recognize that gender and grade level can significantly influence students' perceptions and experiences with STEM education. For instance, male and female students may have different interests, confidence levels, and barriers in engaging with STEM subjects, which could affect their attitudes. Similarly, students in different grades may experience varying levels of exposure to STEM content, impacting their overall perceptions and enthusiasm for these fields. Therefore, further studies are needed to test whether these findings apply in various geographical and cultural contexts, utilizing diverse samples that encompass different gender representations and grade levels. This broader approach will enhance the understanding of how to effectively foster positive attitudes toward STEM among students worldwide. Second, this research used a quantitative design that provides objective data, but did not integrate qualitative methods that could offer deeper insights into the reasons behind students' attitudes toward STEM. Interviews or focus group discussions could improve understanding of the factors that influence student attitudes.

Furthermore, the study focused on gender and grade-level variables without considering other factors such as socioeconomic background, family support, and prior learning experiences, which could also influence students' STEM attitudes. Despite validation through CFA, some statement items did not meet the suitability criteria, indicating that the instrument used requires refinement. Further validation with a larger and more diverse population is necessary to ensure the reliability and validity of the evaluation instrument.

To address these limitations, future research is recommended to expand the sample geographically and demographically. Research should include samples from various regions (i.e., in Indonesia, Asian, Europe, and USA) and consider diverse demographic backgrounds to obtain a more comprehensive picture of student attitudes toward STEM. In addition, employing mixed methods that combine quantitative and qualitative approaches can provide deeper insights into student attitudes. For example, in-depth interviews and focus group discussions can uncover factors that may not be detected through surveys alone.

Future research should also consider other factors, such as socioeconomic background, family support, and teaching quality, that may influence students' STEM attitudes. This can provide a more complete and detailed understanding. Continuous development and validation of the evaluation instruments are also necessary. Involving subject matter experts and education practitioners in the instrument development process can improve the accuracy and relevance of the statement items.

Conducting longitudinal research can also help to understand how attitudes towards STEM develop over time and what factors contribute to these changes. This can provide valuable information for the development of sustainable STEM curricula and learning strategies. Finally, considering the recommendations of Tsai et al. (2023), future research should incorporate comprehensive analyses of demographic, psychological, and environmental factors that can influence students' STEM attitudes.

By considering these limitations and implementing recommendations for future research, it is expected that a deeper and more comprehensive understanding of student attitudes toward STEM and influencing factors can be achieved.

6. Conclusion

In conclusion, this study successfully developed and validated a STEM attitude questionnaire using CFA to assess item reliability. The primary objective was to categorise the statement items based on their conceptual meaning. While CFA generally supported model fit guidelines, several items, particularly negatively worded ones in the mathematics scale, did not meet statistical criteria due to low factor loadings.

The study underscores the importance of aligning the conceptual meaning of statement items with statistical data for comprehensive results. CFA effectively validates theoretical constructs by testing relationships between latent variables and measurable indicators. However, understanding how students interpret the statements is crucial for evaluating the reliability and validity of the instrument. Therefore, the integration of statistical data and contextual insights during instrument development is essential for accurate measurement.

Additionally, the study identified various path coefficients and effect sizes between variables, indicating strong correlations between the STEM attitude variables. High path coefficients suggest substantial relationships between latent variables and their indicators, supported by significant effect sizes that clarify the magnitude of these relationships. Based on these robust findings, the study affirms the validity and reliability of the STEM attitude evaluation instrument in accurately measuring student attitudes. This instrument can serve as a valuable tool for further research aimed at enhancing STEM learning in educational settings. Additionally, the study explored how background factors, such as gender and grade level, influence students' responses to the STEM attitude questionnaire. Although no significant gender differences were found, notable variations based on grade level suggest that longer exposure and greater participation in STEM activities positively impact student attitudes, aligning with previous research.

These insights have important implications for STEM education strategies, emphasising the need for inclusive approaches that promote deep learning experiences for all students, regardless of gender or grade level. Designing specific educational interventions using instruments that measure attitudes toward STEM can effectively identify students' perceptions and areas of improvement. For instance, implementing targeted programs based on the results from attitude assessments can help address specific misconceptions and foster positive attitudes. Additionally, using instruments to monitor changes in attitudes over time can inform curriculum adjustments and teaching strategies, ensuring that interventions remain relevant and impactful. By leveraging these tools, educators can create tailored initiatives that nurture a positive environment for all students in STEM education. Ultimately, such strategies can significantly enhance student engagement and achievement in STEM disciplines, contributing to a more skilled and diverse workforce.

Author´s Contribution

Mujib Mujib: Writing - Original Draft Supervision, Funding acquisition, Formal analysis, Methodology, and Original Draft; Mardiyah Mardiyah, Writing – review & editing, Conceptualization, Writing - Editing, and Visualization.

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