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FACTORS DETERMINING SOCIO-SCIENTIFIC ISSUES IN STEAM EDUCATION TO ENHANCE PROBLEM-SOLVING SKILLS FOR PRE-SERVICE TEACHERS: DEVELOPMENT AND VALIDATION OF A MEASUREMENT MODEL

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ABSTRACT

This study aimed to develop and validate a measurement model of SSI–STEAM education for pre-service science teachers (PSTs), with particular attention to dimensions associated with problem-solving skill development. Using a cross-sectional survey design, data were collected from 173 PSTs enrolled in science education programmes in Indonesia. Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) were conducted to identify and validate the latent constructs underpinning SSI–STEAM implementation. EFA results supported a clear two-factor model, consisting of enacted values and practices, affective learning, authentic contexts and activities, interdisciplinary thinking and integrated practices, and problem-solving skill reflection. CFA confirmed the adequacy of this structure, producing acceptable model-fit indices and satisfactory reliability and convergent validity across factors. To conclude, this study highlights the multidimensional nature of SSI–STEAM education and underscores the importance of value-driven instruction, interdisciplinary integration, authentic socio-cultural contexts, and reflective problem-solving in preparing PSTs to engage learners with complex real-world scientific issues. These insights offer valuable implications for curriculum design in science teacher education, which are also discussed.

Keywords: socio-scientific issue; STEAM education; pre-service science teachers; problem-solving skills

INTRODUCTION

Contemporary educational frameworks, such as those from the Organisation for Economic Co-operation and Development (OECD, 2023), emphasise that modern science education must move beyond rote learning and nurture essential competencies, including problem-solving skills. These competencies are central to the United Nations Sustainable Development Goal 4 (Quality Education), which calls for the development of learners' cognitive, social, and practical skills needed to address complex societal challenges (UNESCO, 2017). Through these skills, students are encouraged to think analytically and creatively in identifying and formulating solutions to real-world problems within scientific contexts (Shanta, 2022; Nilimaa, 2023), thereby making their learning experiences more meaningful and applicable. Fostering students' problem-solving abilities has therefore become a central aim of educational reforms across many countries, shaping the pedagogical directions required in this era (Leite & Dourado, 2013; Verawati & Nisrina, 2025). One promising approach in achieving this goal is the integration of Socio-

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Scientific Issues (SSI) within STEAM education (Alcaraz-Dominguez & Barajas, 2021; Anwar et al., 2024; Guo et al., 2025), which has gained increasing attention in both national and international research. In the context of the Global South, this approach is particularly relevant because it enables science learning to be anchored in locally situated socio-scientific challenges, such as environmental degradation, public health, and sustainability, which might be intertwined with social, cultural, and economic inequalities. Numerous studies have highlighted the importance of embedding SSI in STEAM education, demonstrating that integrating ethical, environmental, and social dimensions in which these issues should be included in science classes to significantly enhance students' problem-solving skills and scientific literacy (Saija et al., 2022; Macalalag et al., 2023; Reswara et al., 2024; Rahayu et al., 2025).

SSI-based STEAM represents a relatively recent interdisciplinary framework that combines socio-scientific issues with STEAM-oriented learning practices (Mang et al., 2023). Within this approach, students utilise scientific concepts to explore real-world socio-scientific problems and participate in actions aimed at addressing these issues. This distinguishes SSI-based STEAM from conventional STEAM instruction, where learning may involve real-world contexts but does not necessarily emphasise socio-scientific problems. It also differs from traditional SSI approaches, which centre primarily on discussing and evaluating socio-scientific issues; although scientific knowledge is involved, the main objective is typically to increase students' awareness and support them in forming informed positions on the issues.

The integration of SSI and STEAM education is compatible as well as complementary, as SSI engages students in the ethical and social dimensions of real-world issues, while STEAM education equips them with the conceptual, technological, and creative tools needed to design innovative solutions. This is because, as Martín-Páez et al. (2019) asserted, the pedagogical value of SSI becomes even more meaningful when combined with approaches grounded in real-world problem-solving. As a result, integrated STEAM education, which emphasises conceptual understanding, critical and creative thinking, and collaborative learning, aligns closely with the primary objectives of SSI-based learning (Wahono et al., 2021; Yulianti et al., 2025). By integrating SSI-STEAM perspectives, teachers can design learning experiences that are both engaging and innovative while linking scientific concepts more meaningfully and authentically to students' daily lives.

For pre-service science teachers (PSTs), the ability to design and facilitate SSI-STEAM learning can be particularly crucial, as they play a central role in shaping students' capacity for critical engagement with science-related societal challenges (Bencze et al., 2020). According to Anabousy and Daher (2022), PSTs are expected to develop learning experiences that integrate scientific knowledge with societal contexts, thereby fostering students' ability to analyse, discuss, and make informed decisions about real-world science and technology issues critically and collaboratively. However, previous studies have shown that many PSTs encounter difficulties in implementing SSI-based STEAM approaches, which may be due to limited pedagogical preparation, fragmented understanding of interdisciplinary connections, and insufficient affective engagement with controversial issues (e.g., Won et al., 2021; Lee, 2022; Mang et al., 2023). These challenges highlight the need for teacher-education programmes that explicitly address the pedagogical, emotional, and contextual dimensions of SSI-based STEAM learning and equip future educators with the problem-solving skills necessary to guide their future students in making evidence-based decisions on complex socio-scientific problems.

According to one recent study by Mang et al. (2021), the defining principles of SSI–STEAM education practices comprise four key dimensions: (1) Enacted Values and Practices, (2) Affective Learning, (3) Authentic Contexts and Activities, and (4) Interdisciplinary Thinking and Integrated Practices. These principles enable teachers to organise and emphasise coherent learning experiences that connect scientific understanding with real-world socio-scientific contexts. In addition, previous research has highlighted the importance of problem-solving skill reflection as a crucial component of implementing SSI–STEAM education effectively. Therefore, it is reasonable to assume that multiple realistic SSI–STEAM education factors are associated with learners' development of problem-solving skill reflection in science classrooms (see Table 1 for a review).

Table 1. Evidence Supporting the Possible Aspects of the SSI-STEAM for Problem-Solving Skills

Factors	Definition	Citations
Enacted values and practices	The extent to which learners apply scientific knowledge alongside their personal, cultural, political, and social values when making decisions, constructing arguments, and engaging in real-world socio-scientific problem-solving.	(Idris et al., 2012; Jacobs et al., 2022; Kumarassamy & Koh, 2019; Mang et al., 2021; Siribunnam et al., 2019)
Affective learning	Learners' emotional, motivational, and attitudinal responses that influence how they engage with SSI-related content, including their capacity to manage emotions, empathise, and sustain interest in complex or controversial issues.	(Chen et al., 2024; Chong et al., 2018; Gao et al., 2021; Mang et al., 2021, 2023; Y. Zhang et al., 2023)
Authentic contexts and activities	Learning experiences situated in meaningful and real-world socio-cultural scenarios that mirror how knowledge, values, and skills are used outside the classroom, thereby deepening relevance and engagement.	(Chang et al., 2024; Herro et al., 2019; Mang et al., 2021; Schriebl et al., 2023; Zeidler, 2016)
Interdisciplinary thinking and integrated practices	The ability to draw on and connect concepts, methods, and perspectives from multiple disciplines, such as STEAM, to analyse and address socio-scientific problems.	(Heim et al., 2025; Herro et al., 2019; Macalalag et al., 2020; Mang et al., 2023; Nugraha et al., 2024)
Problem-solving skills reflection	Learners' capacity to monitor, evaluate, and adjust their reasoning and strategies when solving complex SSI-related problems, including weighing evidence, considering multiple perspectives, and justifying decisions.	(Mang et al., 2023; Pinar et al., 2025; Pulungan et al., 2025; Topsakal et al., 2022; Wahono et al., 2021)

The principle of enacted values and practices refers to learners' ability to apply scientific knowledge in ways that reflect the personal, cultural, political, and social values shaping their everyday decisions, a capacity that Mang et al. (2021) identify as fundamental to scientific literacy (Sjöström et al., 2017; Lee & Brown, 2018; Kruse et al., 2025). Because these underlying values strongly influence how individuals act within society, SSI-based STEAM learning should create opportunities for students to practise using socio-cultural and political values when making decisions, constructing arguments, and solving real-world problems (Kumarassamy & Koh, 2019; Siribunnam et al., 2019; Mang et al., 2021). Such opportunities can move students beyond classroom learning by enabling them to participate as active socio-cultural and political agents and to develop the dispositions of responsible global citizens committed to addressing complex societal issues (Jacobs et al., 2022). To support this development, Idris et al. (2012) argued that teachers are encouraged to foster a safe and supportive environment where learners can explore and negotiate different values and perspectives, reflect on their own beliefs, and shape the identities they wish to enact in their personal and societal lives.

Students' affective learning play a significant role in shaping both their cognitive growth and behavioural responses, linking the learning process with the context in which learning takes place (Chong et al., 2018; Mang et al., 2021). Chen et al. (2024) describe the affective domain as comprising multiple components, including motivation, attitudes, and self-efficacy. These aspects influence how learners participate in instructional activities and interpret their learning experiences. Educators can promote affective engagement by implementing strategies such as facilitating discussions that consider diverse viewpoints, connecting scientific ideas to real-world situations, and designing hands-on activities that support active involvement (Zhang et al., 2023). Nevertheless, many socio-scientific issues involve personal, ethical, and moral considerations that may trigger strong emotional reactions among students (Gao et al., 2021; Mang et al., 2023). For this reason, Gao et al. (2021) recommend that teachers support students in recognising their emotional responses, managing emotionally complex situations, and cultivating affective skills such as empathy.

To prepare students for real-life situations, as Chang et al. (2024) and Mang et al. (2021) argued, it is essential that they are provided with authentic contexts and activities because this principle helps to bridge their experiences inside and outside the classroom, making learning more meaningful and impactful. It underscores the need to use instructional content that situates students within contextually relevant and authentic real-world problems and tasks (Herro et al., 2019; Zeidler, 2016). Authentic contexts are learning scenarios that mirror how knowledge, values, and skills are applied in everyday life (Schriebl et al., 2023). However, it is vital that science learning is contextualised through scenarios that also hold socio-cultural relevance (Schriebl et al., 2023). Real-world situations that are connected to students' socio-cultural backgrounds are more likely to stimulate curiosity and interest, thereby motivating deeper engagement with scientific concepts (Chang et al., 2024).

Interdisciplinary thinking and integrated practices emphasise that students ought to be given opportunities to critically discuss and apply interdisciplinary thinking and integrated practices (Herro et al., 2019; Nugraha et al., 2024). Interdisciplinary thinking is the ability to consider and apply perspectives from multiple disciplines when solving problems, whereas integrated practices refers to the ability to draw on skills informed by multiple disciplines and apply them to new experiences (Heim et al., 2025). However, Macalalag et al. (2020) asserted that in the science context, the programme connects learning to socio-cultural and political perspectives and values, allowing students to connect emotionally with the scientific content. This has been shown to increase motivation and interest in social action, as well as help students develop strong character (Mang et al., 2023).

Problem-solving skills reflection refers to learners' ability to monitor, evaluate, and refine their strategies when analysing and resolving complex problems, which is a competency that is widely emphasised in contemporary science and STEM education (Pinar et al., 2025). Research shows that iterative STEM activities encourage students to assess their reasoning, consider alternative approaches, and judge the effectiveness of their solutions (Zeeshan et al., 2021; Hebebci & Usta, 2022; Topsakal et al., 2022). This reflective process is even more crucial in SSI contexts, where learners must navigate problem situations that are uncertain, value-laden, and socially embedded. SSI-based learning requires students to weigh evidence, consider diverse perspectives, and justify their decisions, which are the practices that naturally promote deeper metacognitive reflection (Wahono et al., 2021). Additionally, SSI instruction commonly employs open-inquiry approaches that allow students to engage with scientific content through problems or cases that are inherently controversial and open-ended (Mang et al., 2023). Recent studies also demonstrate that integrating SSI tasks into science learning strengthens students' ability to evaluate solutions and make evidence-based judgements about real-world socio-environmental challenges (Pulungan et al., 2025). For PSTs, cultivating reflective problem-solving skills is essential, as it prepares them to guide learners through complex and socially relevant scientific problems.

As noted earlier, although several studies have examined the impact of SSI–STEAM education on students' problem-solving skills in science instruction, only a limited number of empirical investigations have explored the underlying dimensions of SSI–STEAM education itself. For instance, Mang et al. (2021) primarily defined the guiding principles of SSI–STEAM education within the context of higher education but did not proceed to the stage of instrument development or construct validation. Another study by Baek et al. (2022) developed and implemented an SSI–STEAM programme in an elementary school context in South Korea, focusing on instructional design rather than measurement modelling. Similarly, although Mang et al. (2023) developed a rubric for evaluating SSI-based STEAM teacher implementation and programme development in secondary school science education, there remains a gap in the development and psychometric validation of an instrument designed to confirm the factors determining PSTs' engagement with and implementation of SSI–STEAM education in relation to problem-solving skills.

Therefore, the purpose of this study was to address the following overarching research question: What is the underlying factorial structure of SSI-STEAM education that contributes to the enhancement of problem-solving skills in science classrooms? To answer this question, the present study employed Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) to develop and validate the key factors that determine the effective implementation of SSI-STEAM approaches within science teacher education programmes. The novelty offered by this study lies in the empirical development and validation of the underlying factorial structure of SSI–STEAM education for PSTs within a single and coherent measurement model.

METHODS

This study employed a cross-sectional research design using a questionnaire to examine the underlying influences on SSI–STEAM education for problem-solving skills as perceived by PSTs. The Indonesian questionnaire was developed by the authors by incorporating and adapting items previously used by other researchers. The survey consisted of three types of questions. First, the initial page of the questionnaire provided information about the study, participants' rights, and their voluntary consent to participate. If participants agreed, they proceeded to the next section containing dichotomous questions on gender, year of study, and major. Third, participants were asked to rate their views on SSI–STEAM education for problem-solving skills using a 5-point Likert agreement scale across five dimensions: enacted values and practices (EV), affective learning (AL), authentic contexts and activities (AC), interdisciplinary thinking and integrated practices (IT), and problem-solving skills reflection (PS). A total of 29 initial items were used (see Appendix 1), with response options ranging from 1 (strongly disagree) to 5 (strongly agree).

Validity refers to the degree to which the interpretation of test results aligns with its intended purpose and is supported by theoretical and empirical evidence (Markus & Borsboom, 2024). The validation of an instrument may be conducted through verification of its internal aspects, namely its components and procedures, as well as through examination of its external use and impact. According to Clark and Watson (2019), instrument validity encompasses several forms, including criterion validity, content validity, and construct validity. Content validity relies on expert judgment, in which specialists evaluate the instrument's components, structure, and potential implementation. An instrument can be considered valid if experts agree that it appropriately measures the competencies or constructs it is intended to assess (Markus & Borsboom, 2024). Furthermore, quantitative indices, such as Aiken's V coefficient (Aiken, 1985), may be applied to determine the level of expert agreement. The attitude scale was evaluated by five validators representing expertise in science education, linguistics, and psychology. The validators assessed each item by examining the alignment between the constructs, indicators, and statements. The results indicated that all items were considered valid, as the Aiken's V coefficients reached values of $V \geq 0.75$ based on ratings from the five validators using a four-point response scale (Aiken, 1985).

In terms of participants, Hair Jr. et al. (2022) recommend using power analysis software such as GPower 3.1 in accordance with the specifications of the proposed model. This process involves specifying the expected effect size along with the significance levels for alpha (α) and statistical power (β). Conventionally, an alpha level of .05 and a power level of 80 percent are deemed acceptable. In this study, five predictors (EV, AL, AC, IT, and PS) were included, and the analysis assumed an average effect size of 0.15, an alpha of .05, and a power of .95, following Cohen's (1994) guidelines. The power analysis indicated that a minimum of N = 138 participants was required. Data were collected by distributing an online questionnaire to PSTs across several subject areas and academic levels, including Bachelor's and Master's programmes in Science Education, Physics Education, and Biology Education, all of whom had taken a STEAM learning course. After screening responses, a final dataset of 173 PSTs was obtained for analysis. This sample size exceeded the minimum requirement suggested by the GPower 3.1 calculation, as presented in Table 2.

Table 2. Participants Demography

Category	Subcategory	N (%)
Gender	Male	25 (14.5)
	Female	148 (85.5)
Educational Level	Bachelor	136 (78.6)
	Master	37 (21.4)
Major	Science Education	119 (68.8)
	Physics Education	53 (30.6)
	Biology Education	1 (0.6)

Data analysis proceeded in two main stages using Jamovi 2.6.26 software assistance. First, an EFA was conducted to identify the latent structure underlying the SSI–STEAM questionnaire. Prior to analysis, data were screened for normality, outliers, and missing values, and suitability for factor analysis was confirmed through the Kaiser–Meyer–Olkin (KMO) measure (exceeding the recommended level of .60) and Bartlett's test of sphericity (acceptable if reached a statistical significance at $p < .001$) (Kaiser, 1974; Hoelzle & Meyer, 2013). EFA was conducted using the minimum residual extraction method with oblimin rotation, given the theoretical expectation of correlated factors. The number of factors was determined through parallel analysis. All loadings were examined without suppression. A minimum loading threshold of .50 was applied for item retention. Items were evaluated for cross-loadings (≥ .30 on more than one factor). Meanwhile, items with weak loadings or problematic cross-loadings were removed. This iterative process yielded a stable two-factor structure.

Subsequently, CFA using maximum likelihood estimation was employed to validate the measurement model. Model fit was evaluated using several commonly recommended indices (Bentler, 1990; Hooper et al., 2008; Kline, 2010). These included the chi-square statistic (χ^2), the normed chi-square ratio (χ^2/df), the comparative fit index (CFI), the standardised root mean square residual (SRMR), and the root mean square error of approximation (RMSEA). A χ^2/df value below 3.0 indicates an acceptable fit, CFI values above .95 suggest good model fit, SRMR values below .05 indicate acceptable residuals, and RMSEA values below .08 reflect a reasonable approximation of model fit. Finally, as for the reliability, Peterson et al. (2020) argued that CR values of at least 0.70 and AVE values of 0.40 or higher were considered evidence of adequate reliability.

RESULTS AND DISCUSSION

EFA aims to identify the number of factors generated by the data, the loadings of each factor, and the percentage of variance explained by the factors. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was acceptable with values of 0.959, identifying the adequate sample and exceeding the recommended level of 0.60, and Bartlett's test of sphericity reached a statistical significance (chi-square of 3779 with 276 degrees of freedom) at $p < 0.001$. Overall, these measurements revealed that the correlation matrix for EFA was appropriate. To determine the underlying factor structure of the SSI–STEAM questionnaire, an EFA was conducted using the minimum residual extraction method with an oblimin rotation. Parallel analysis was used to guide factor retention, and the results indicated a two-factor solution. These two factors together accounted for a substantial proportion of shared variance and met the criteria for further examination. Item communalities, factor loadings, and the number of items per factor were then reviewed following the guidelines of Hair et al. (2021). During this iterative refinement, eight items were removed because they either exhibited low loadings, problematic cross-loadings, or insufficient conceptual alignment with the emergent factors. No factors were removed, as each retained factor was represented by at least three items, thus meeting the minimum criterion for interpretability. The final EFA solution retained 21 items across five interpretable factors.

As shown in Table 3, the first factor comprised items from AL, AC, IT, and PS, with loadings ranging from 0.548 to 0.913. The second factor comprised the five EV items, which loaded strongly between 0.506 and 0.912. The revised EFA model of SSI-STEAM learning for problem-solving skills produced satisfactory sampling adequacy indices, with a KMO value of 0.964, and Bartlett's test of sphericity reaching statistical significance ($\chi^2 = 3474$, df = 231, $p < 0.001$), indicating that the data were suitable for factor analysis. The ratio of participants to items in the final model met recommended standards for factorial stability and interpretability.

Table 3. Exploratory Factor Analysis and Factor Loadings of the SSI-STEAM for Problem-Solving Skills Retained Items

Item No.	Scales	Factor		Uniqueness
		1	2	
1	EV1		0.782	0.343
2	EV2		0.506	0.583
3	EV3		0.690	0.394
4	EV4		0.789	0.347
5	EV5		0.912	0.251
6	AL1	0.548		0.356

Item No.	Scales	Factor		Uniqueness
		1	2	
7	AL2		0.587	0.348
8	AL3		0.705	0.432
9	AC1	0.589		0.318
10	AC2	0.776		0.379
11	AC3	0.771		0.303
12	AC4	0.568		0.398
13	IT1	0.896		0.358
14	IT2	0.647		0.238
15	IT3	0.787		0.475
16	IT4	0.633		0.316
17	IT5	0.669		0.267
18	PS1	0.886		0.305
19	PS2	0.812		0.325
20	PS3	0.913		0.277
21	PS4	0.847		0.228
22	PS5	0.886		0.263

To determine the number of factors to retain, a minimum residual extraction with oblimin rotation was conducted, and parallel analysis was used as the primary decision criterion. The initial eigenvalues indicated that only the first factor exceeded Kaiser's threshold of 1 ($\lambda = 13.54$), with all subsequent eigenvalues falling below 1 (e.g., $\lambda_2 = 0.83$; $\lambda_3 = 0.33$). The scree plot displayed a clear and steep inflection after the first component, with the observed eigenvalues crossing below the simulated eigenvalues at the second component, confirming that only two factors were statistically supported for retention (Figure 1). Factor statistics further showed that Factor 1 accounted for 43.6% of the total variance, while Factor 2 accounted for an additional 22.3%, resulting in a cumulative explained variance of 65.9%. Both factors, therefore, contributed meaningfully to the overall structure. Inter-factor correlations indicated a strong positive association (r = 0.801), which justified the use of an oblique rotation method. The combined evidence from parallel analysis, eigenvalues, and the scree plot supported the adequacy of the two-factor solution for subsequent interpretation. Furthermore, Cronbach's alpha coefficient indicated acceptable internal consistency for the entire questionnaire ($\alpha = 0.972$).

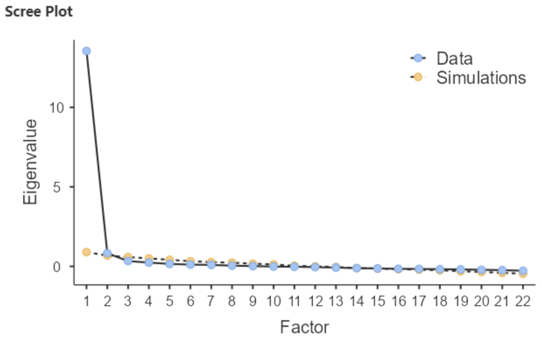

Figure 1. Scree plot for EFA with Oblimin Rotation of SSI-STEAM education for Problem-Solving Skills Scale Items

The two-factor solutions indicate that PSTs tended to perceive the multiple dimensions of SSI–STEAM education as broader and more integrated constructs rather than as five distinct components. Although the theoretical framework delineates all factors (i.e., EV, AL, AC, IT, and PS) as separate principles (Mang et al., 2021, 2023), the empirical patterns in the EFA suggested substantial overlap among these dimensions. This consolidation into two factors may reflect the comprehensive nature of SSI–STEAM education, where emotional engagement, contextual authenticity, interdisciplinary reasoning, and reflective problem-solving are experienced simultaneously in practice rather than as isolated pedagogical features (Johnson et al., 2020; Baek et al., 2022; Macalalag et al., 2020, 2023). In particular, the first factor seemed to capture integrated pedagogical–cognitive dimension, such as contextualised inquiry, interdisciplinary integration, and reflective reasoning, while the second factor primarily represented an enacted values dimension underlying SSI–STEAM implementation.

Similar patterns of dimensional convergence have been observed in studies of socio-scientific and context-based science education, where learners often do not differentiate sharply between cognitive, contextual and affective aspects of instruction due to their interdependent nature in real-world problem contexts (Chowdhury et al., 2022; Potgieter et al., 2025). For example, affective states such as emotions and motivation influence cognitive processes like thinking and reasoning, and the contextual setting integrates both these aspects as learners apply knowledge in real-life situations. This interdependence makes clear-cut distinctions difficult for learners, as learning involves simultaneous cognitive, emotional, and contextual engagements that shape understanding and problem-solving (Li et al., 2023). As a result, the two-factor EFA structure does not contradict the theoretical model, but it highlights the tendency of PSTs to perceive SSI–STEAM pedagogy as an integrated learning approach.

As the EFA supported a two-factor structure, the CFA was conducted to evaluate the adequacy of this measurement model. Although the EFA suggested a two-factor empirical clustering of items, Watkins (2018) asserted that exploratory factor analysis is inherently data-driven and does not require a pre-specified theoretical factor structure. In contrast, CFA explicitly builds on theory by specifying in advance which items load on which factors and testing that hypothesised structure (Xiong et al., 2025). Given that the SSI–STEAM framework is strongly grounded in prior theory delineating five distinct but interrelated domains (i.e., EV, AL, AC, IT, and PS) (Mang et al., 2021, 2023), a CFA was conducted to test the adequacy of the theoretically hypothesised five-factor measurement model. In this sense, the CFA served as a theory-driven evaluation to determine whether the five constructs could be empirically distinguished despite their high intercorrelations observed in the EFA. This approach follows common practice in scale validation, where EFA is used to explore potential dimensionality, while CFA is employed to test theoretically specified measurement models and assess whether the hypothesised constructs can be empirically distinguished (Ferrando & Lorenzo-Seva, 2018; Orçan, 2018).

The analysis was performed using full information maximum likelihood estimation, with factor variances constrained to 1. Standardised coefficients were examined to assess the strength of the relationships between indicators and their respective latent constructs. The resulting factor loadings ranged from 0.447 to 0.580 for EV, 0.536 to 0.579 for AL, 0.546 to 0.589 for AC, 0.551 to 0.651 for IT, and 0.582 to 0.648 for PS (see Table 4), with the path diagram presented in Figure 2. The overall model demonstrated acceptable fit to the data. The chi-square statistic was significant, $\chi^2(199) = 372.00$, $p < 0.001$, which is expected for complex models with moderate sample sizes. The chi-square to degrees of freedom ratio ($\chi^2/df = 1.87$) was below the recommended threshold of 3.0, indicating an acceptable degree of discrepancy between the observed and model-implied covariance matrices. Additional fit indices also indicated satisfactory model performance: CFI = 0.950, TLI = 0.941, SRMR = 0.0359, and RMSEA = 0.0710 (90% CI [0.0598, 0.0820]). Although the RMSEA slightly exceeded the ideal value of .06, it remained within the acceptable range of 0.05 – 0.08. Furthermore, the composite reliability (CR) values for all five latent constructs exceeded the recommended 0.70 threshold, and the AVE values < 0.40 but CR > 0.60 are still acceptable if loadings are significant, indicating that the model demonstrates adequate internal consistency and convergent validity.

Table 4. Confirmatory Factor Analysis of SSI–STEAM Education for Problem-Solving Skills

Factor	Indicator	Estimate	SE	Z	p	CR	AVE
Enacted Values and Practices	EV1	0.528	0.0407	12.97	<0.001	0.861	0.297
	EV2	0.447	0.0470	9.51	<0.001		
	EV3	0.562	0.0467	12.03	<0.001		
	EV4	0.553	0.0431	12.82	<0.001		
	EV5	0.580	0.0420	13.80	<0.001		
Affective Learning	AL1	0.567	0.0444	12.77	<0.001	0.758	0.309
	AL2	0.579	0.0445	13.02	<0.001		
	AL3	0.536	0.0476	11.25	<0.001		
Authentic Contexts and Activities	AC1	0.574	0.0437	13.12	<0.001	0.814	0.323
	AC2	0.585	0.0483	12.10	<0.001		
	AC3	0.589	0.0446	13.20	<0.001		
	AC4	0.546	0.0450	12.12	<0.001		
Interdisciplinary Thinking & Integrated Practices	IT1	0.551	0.0452	12.20	<0.001	0.869	0.361
	IT2	0.597	0.0409	14.61	<0.001		
	IT3	0.596	0.0543	10.98	<0.001		
	IT4	0.555	0.0420	13.21	<0.001		
	IT5	0.651	0.0456	14.30	<0.001		
Problem-Solving Skill Reflection	PS1	0.582	0.0428	13.58	<0.001	0.880	0.386
	PS2	0.601	0.0448	13.42	<0.001		
	PS3	0.616	0.0432	14.25	<0.001		
	PS4	0.648	0.0435	14.89	<0.001		
	PS5	0.631	0.0438	14.42	<0.001		

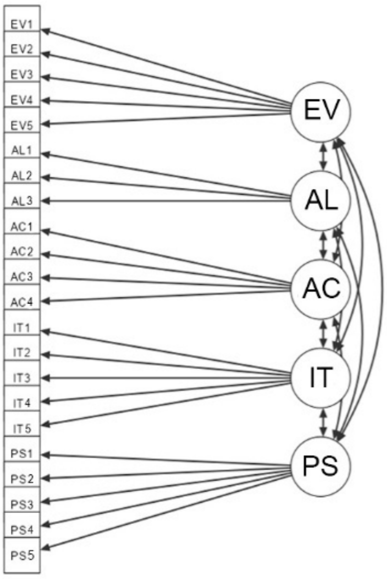

Figure 2. Path Diagram of CFA Results for the SSI-STEAM Education for Problem-Solving Skills

The CFA results demonstrate strong psychometric reliability and suggest that the measurement model aligns conceptually with the multi-dimensional nature of SSI-STEAM instruction identified in previous literature (Ke et al., 2021; Klaver & van der Molen, 2021; Kim & Na, 2022; Tang et al., 2025). The strong loadings for EV, AC, and IT in particular reinforce arguments from recent SSI-STEAM scholarship that meaningful engagement with socio-scientific contexts requires the integration of values-oriented reasoning, authentic scenario-based learning, and interdisciplinary sense-making (Herro et al., 2019; Mang et al., 2021). This further supports the theoretical model proposed by Mang et al. (2023), who assert that SSI-STEAM learning is anchored in four mutually reinforcing principles: enacted values, affective engagement, authenticity, and interdisciplinary integration.

The PS factor, while not explicitly named by Mang et al. (2023), can be seen as complementary to these pillars. For PSTs, reflective problem-solving is a critical professional competency because it underpins their ability to guide learners through complex, uncertain, and value-laden socio-scientific issues (Zeidler et al., 2009; Klosterman & Sadler, 2010). PSTs are required to not only solve problems themselves, but also understand how they solve problems, which encompasses monitoring their reasoning, evaluating the adequacy of their judgments, and adjusting their strategies when encountering new or ambiguous scenarios. According to Baek et al. (2022), such reflective capacities enable PSTs to design learning experiences that foster inquiry, evidence evaluation, and multi-perspective reasoning among their future students. The inclusion of PS reflection also finds support in the science teacher education literature. For example, W.-X. Zhang and Hsu (2025) highlighted that reflective practices are pivotal in helping teachers and learners to integrate new pedagogical approaches. This implies that PSTs should not only practise SSI–STEAM activities but also explicitly reflect on the problem-solving process. This mirrors recommendations that teacher preparation should build epistemic frames encompassing knowledge, skills, identity and values, where all of which evolve through reflective engagement.

The factor covariance estimates showed that all five latent constructs were strongly and significantly associated with one another, as shown in Table 5. EV demonstrated high positive covariances with AL (0.919, $p < 0.001$), AC (0.873, $p < 0.001$), IT (0.856, $p < 0.001$), and PS (0.792, $p < 0.001$), indicating that learners who perceive stronger enacted socio-cultural values also tend to report higher affective engagement, more authentic contextualisation, greater interdisciplinary integration, and stronger reflective problem-solving. AL likewise showed strong relationships with AC (0.941, $p < 0.001$), IT (0.914, $p < 0.001$), and PS (0.878, $p < 0.001$), suggesting that affective engagement is closely intertwined with contextual, interdisciplinary, and reflective components of SSI-STEAM learning. AC demonstrated extremely high covariances with IT (1.005, $p < 0.001$) and PS (0.971, $p < 0.001$), reflecting the integrated nature of authentic real-world contexts, interdisciplinary practices, and problem-solving reflection. Finally, IT was also strongly related to PS (0.950, $p < 0.001$), indicating that interdisciplinary engagement is closely associated with learners' reflective problem-solving processes. However, the very high latent correlations observed among several constructs, including one estimate slightly exceeding unity, indicate substantial overlap among the SSI–STEAM dimensions. Such magnitudes suggest potential multicollinearity and limited discriminant validity within this sample. This pattern is still theoretically plausible, as these pedagogical elements are enacted simultaneously in authentic SSI–STEAM instruction (Mang et al., 2021, 2023). Nevertheless, the strength of these associations may also signal the presence of a broader higher-order structure underlying the five first-order constructs.

Table 5. Standardised Factor Correlations among SSI–STEAM Education for Problem-Solving Skills Constructs

		Estimate	SE	Z	p
Enacted Values and Practices	Enacted Values and Practices	1.000			
	Affective Learning	0.919	0.0263	34.9	<0.001
	Authentic Contexts and Activities	0.873	0.0292	29.9	<0.001
	Interdisciplinary Thinking & Integrated Practices	0.856	0.0291	29.4	<0.001
	Problem-Solving Skill Reflection	0.792	0.0356	22.3	<0.001
Affective Learning	Affective Learning	1.000			<0.001
	Authentic Contexts and Activities	0.941	0.0257	36.6	<0.001
	Interdisciplinary Thinking & Integrated Practices	0.914	0.0261	35.0	<0.001
	Problem-Solving Skill Reflection	0.878	0.0298	29.5	<0.001

		Estimate	SE	Z	p
Authentic Contexts and Activities	Authentic Contexts and Activities	1.000			
	Interdisciplinary Thinking & Integrated Practices	1.005	0.0131	76.8	<0.001
	Problem-Solving Skill Reflection	0.971	0.0151	64.2	<0.001
Interdisciplinary Thinking & Integrated Practices	Interdisciplinary Thinking & Integrated Practices	1.000			<0.001
	Problem-Solving Skill Reflection	0.950	0.0150	63.5	<0.001
Problem-Solving Skill Reflection	Problem-Solving Skill Reflection	1.000			

Socio-scientific problems, by design, require learners to draw on scientific, ethical, technological, and socio-cultural perspectives simultaneously (Klaver & van der Molen, 2021). The results of this CFA empirically support this theoretical view, suggesting that PSTs who perceive themselves as capable of integrating knowledge across disciplines are more likely to demonstrate stronger engagement with SSI-STEAM practices. This aligns with Cook et al. (2020), who reported that interdisciplinary competencies enhance learners' capacity to navigate real-world challenges.

Finally, the model fit indices (CFI = 0.950; TLI = 0.941; RMSEA = 0.071; SRMR = 0.0359) indicate an overall good fit. These values meet or closely approach commonly accepted benchmarks in science education measurement studies (e.g., CFI/TLI $\geq$ 0.90, RMSEA $\leq$ 0.08). Similar fit levels are reported in instruments developed in SSI and STEAM contexts, such as rubrics for evaluating SSI-based STEAM programmes (Mang et al., 2023), interdisciplinary science learning frameworks (Herro et al., 2019), and SSI-informed scientific literacy models (Zeidler et al., 2009). The strength of the fit reinforces the five-factor model's correspondence with theoretical expectations, reflecting coherent dimensions of SSI-STEAM learning as perceived by PSTs.

This study has several limitations. First, the sample was limited to Indonesian PSTs, which may restrict the generalisability of the findings to other cultural or institutional contexts where perceptions of SSI–STEAM education may differ. In addition, the representativeness of certain subgroups was limited, as some majors (e.g., Biology) were underrepresented in the sample, as well as a gender imbalance, which may have influenced the stability of parameter estimates and the factor structure, potentially limiting the robustness of subgroup interpretations. Second, the cross-sectional design captures PSTs' perceptions at only one point in time and therefore cannot account for developmental changes that might occur as they progress through their teacher education programmes. Third, this study concerns the very high inter-factor correlations identified in the CFA model, which suggest potential multicollinearity and reduced discriminant validity among certain constructs. Although the five-factor solution demonstrated acceptable overall model fit, the substantial overlap among dimensions indicates that they may represent closely integrated components of a broader pedagogical framework. Finally, the study did not include direct measures of scientific content knowledge, socio-scientific reasoning, or engineering competencies, meaning that important cognitive components of SSI–STEAM instruction were not assessed alongside the identified factors.

Future research incorporating broader samples, longitudinal designs, and cognitive performance measures would help provide a more comprehensive understanding of SSI–STEAM readiness among PSTs. Furthermore, exploring alternative structural specifications, such as higher-order or bifactor models, and validating the scale across different samples can further assess construct distinctiveness. For PSTs, the study underscores the importance of reflective problem-solving competency as a core professional skill needed to guide students through value-laden issues. The strong loadings of PS and IT indicate that PSTs benefit from structured opportunities to analyse cases, evaluate their reasoning, justify decisions, and revise strategies, which are practices that are emphasised in SSI studies (e.g., Çalik & Wiyarsi, 2025; Falah et al., 2024; Ke et al., 2021). Teacher-education programmes (e.g., LPTK) should therefore embed SSI-STEAM learning cycles, reflective journals, microteaching simulations, and interdisciplinary project tasks that mirror real-world pedagogical challenges, which are needed for further investigations. Such preparation may enable PSTs to develop adaptive expertise, pedagogical resilience, and confidence in facilitating socio-scientific inquiry in their future classrooms (Bicaj et al., 2024).

Furthermore, the empirically supported dimensions may serve as a framework for structuring SSI-STEAM-oriented coursework by explicitly integrating authentic socio-scientific contexts, interdisciplinary task design, and reflective problem-solving activities into PST training. For example, teacher preparation courses can incorporate structured lesson-planning tasks requiring PSTs to design SSI-based projects that connect multiple STEM disciplines while embedding value-oriented discussions and real-world decision-making scenarios. In addition, assessment practices may align with these dimensions by evaluating conceptual understanding, students' reflective reasoning, integrative thinking, and the application of knowledge to authentic problems.

CONCLUSION

The EFA findings indicated a broader two-factor structure underlying SSI–STEAM implementation (i.e., values-driven, authentic instruction and integrated, reflective problem-solving), whereas the CFA supported a measurement model comprising five interrelated first-order constructs. Taken together, these results highlight the need for teachers to design learning experiences that move beyond procedural STEM activities toward socio-culturally grounded inquiry. Thus, classroom practice should prioritise activities that situate scientific concepts within authentic socio-scientific contexts, allowing learners to negotiate values, engage with multiple viewpoints, and practise evidence-based decision-making. Since these pedagogical moves foster both cognitive and affective engagement, teachers need deliberate strategies for facilitating discussions on contentious issues that could support emotional responses and help students reason through uncertainty.

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