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Structural Equation Modeling of Sustainability Consciousness among Indonesian Pre-Service Chemistry Teachers

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Abstract: Sustainability Consciousness is an important competency for pre-service chemistry teachers, as it encompasses knowledge, attitudes, and behaviours related to environmental, social, and economic sustainability. However, the development and interrelationship of these dimensions among pre-service chemistry teachers in Indonesia have not been sufficiently examined. This study aims to analyze the multidimensional structure of Sustainability Consciousness and examine the relationships among Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours. A quantitative correlational-causal approach was employed involving pre-service chemistry teachers from five teacher education institutions in Indonesia. Data were collected using an adapted Sustainability Consciousness Questionnaire consisting of statements measuring knowingness, attitudes, and behaviours across environmental, social, and economic dimensions. The questionnaire was administered using a five-point Likert scale. Data were analyzed using Covariance-Based Structural Equation Modeling through confirmatory factor analysis and structural model assessment. The results indicate that Sustainability Consciousness is a multidimensional construct reflected through Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours. The descriptive findings show that participants demonstrated very high levels of sustainability knowingness and attitudes, while their sustainability behaviours were comparatively lower. The measurement model demonstrated adequate reliability and validity, while the final model showed an acceptable level of overall fit. The findings indicate a potential gap between sustainability knowledge, attitudes, and behaviours, particularly in translating positive sustainability orientations into consistent practices. Therefore, chemistry teacher education should provide more contextual and action-oriented learning experiences that enable pre-service teachers to transform sustainability knowledge and attitudes into sustainable behaviours.

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INTRODUCTION

In the era *of Society* 5.0, which is marked by convergence between cutting-edge technology and dynamic social and global society, the world is faced with a crisis environment, climate change, energy vulnerability, as well as an increasingly complex set of sources of power. Reports from various international bodies confirm that 21st-century problems are systemic, dynamic, and interconnected, and therefore cannot be solved through a purely linear and reductionist approach (UNESCO, 2020; World Economic Forum, 2023) . In response to these macro challenges, the United Nations, through its Sustainable Development Goals (SDGs) agenda, explicitly positions education as a key institution for transformation towards sustainable development (UNESCO, 2020) . Higher education institutions have an imperative to integrate the principles of Education for Sustainable Development (ESD) into their core academic frameworks to produce graduates who master sustainability competencies. However, this transformation demands a fundamental reorientation in how science is taught, in which mastery of abstract theories must be harmoniously integrated with the values of social and ecological responsibility.

Science education, particularly the exact sciences, is at the forefront of shaping human perspectives on the sustainability of the Earth and the analysis of complex problems. However,

international assessments such as the OECD's Programme for International Student Assessment (PISA) indicate that students in developing countries, including Indonesia, still lack the ability to solve complex problems in real-world contexts (Cordoba-Pachon, 2020; da Costa Junior *et al.*, 2021) . This situation indicates a significant gap between the demands of global competency and science learning practices, which are still predominantly procedural, fragmented, and oriented towards conceptual memorization (Mahaffy *et al.*, 2020) . Science learning in higher education has historically tended to isolate natural phenomena from real-world contexts and ignore the complex interactions between human activities and ecosystems. This fragmented approach has proven unsuccessful in providing students with a holistic understanding of the impact of scientific decisions on global ecological stability.

Within the realm of science, chemistry education holds a crucial yet challenging position. Chemistry is a central discipline that holds the key to various green innovations, such as renewable energy, waste management, biogeochemical cycles, and environmentally friendly materials (Matlin *et al.*, 2021). However, traditional chemical practices and perceptions are often identified as major contributors to environmental pollution and the risks posed by hazardous chemicals. This complexity is compounded by the fact that chemistry instruction in higher education still heavily emphasises isolated algorithmic-numerical problem solving with minimal integration of sustainability issues (Jackson & Hurst, 2021; Pazicni & Flynn, 2019; Vo *et al.*, 2025) . As a result, students are often technically skilled at calculating mathematical equations, but experience significant difficulties when faced with real-world problems involving interactions between chemical, environmental, social, and economic dynamics (Castañeda-Burciaga *et al.*, 2026; Elsawah *et al.*, 2022) .

This pedagogical gap in chemistry education has particularly critical implications for Indonesian pre-service chemistry teachers. As a developing nation navigating pressing socio-ecological challenges—such as industrial waste management, environmental degradation, and energy transition—Indonesia urgently requires environmentally conscious science educators. Prospective chemistry teachers must not only master academic content but also possess the capacity to transform that knowledge into meaningful, sustainability-oriented learning experiences (Akaygun & Aslan-Tutak, 2021; Eilks, 2021). Ideally, prospective chemistry teachers should demonstrate a high level of Sustainability Consciousness, a comprehensive multidimensional construct encompassing knowledge, attitudes, and behaviours across environmental, social, and economic pillars (Arantes & Sousa, 2025; Gericke et al., 2019). However, chemistry teacher education curricula in Indonesia remain heavily skewed toward theoretical content mastery. Consequently, pre-service teachers frequently experience a disconnect between their academic understanding of chemistry and their daily commitment to sustainable practices (Burmeister & Eilks, 2013; Jegstad & Koballa, 2014; Zowada et al., 2020).

To establish rigorous theoretical grounding and conceptual clarity, it is essential to distinguish Sustainability Consciousness (SC) from related constructs, specifically Environmental Literacy (EL) and Sustainability Literacy (SL) (Sanchez et al., 2025) . According to the typology established by Sanchez et al. (2025), Environmental Literacy focuses predominantly on cognitive knowledge and affective dispositions toward natural ecological systems, whereas Sustainability Literacy emphasises broader interdisciplinary problem-solving competencies involving integrated socio-economic and ecological systems. In contrast, Sustainability Consciousness represents a distinct socio-psychological construct. Grounded in the Sustainability Consciousness Questionnaire (SCQ) framework (Arantes & Sousa, 2025; Gericke et al., 2019), SC integrates an individual's Knowingness (cognitive aspect), Attitudes (affective aspect), and Behaviours (action-oriented aspect) across the three constituent pillars of sustainable development: environmental, social, and economic. In this study, the term "Sustainability Consciousness" is consistently adopted as the overarching construct to prevent terminological overlap with general environmental awareness or sustainability literacy.

Although various environmental evaluation instruments have been implemented globally, a critical empirical and methodological gap remains in the Indonesian science education literature. Most local studies assessing prospective teachers' environmental orientations have relied on qualitative descriptive evaluations, single-pillar ecological measurements, or simple bivariate analyses that fail to model the dynamics of structural pathways (Zulkarnaen et al., 2023). While qualitative approaches offer valuable contextual insights into individual perceptions, they are inherently constrained in empirically validating

structural relationships, testing mediating mechanisms, or confirming measurement validity across multi-institutional populations. Conversely, quantitative approaches that rely solely on descriptive surveys fail to explain the structural pathways through which cognitive knowledge translates into affective attitudes and actionable behaviours. To address these specific limitations, this study employs Covariance-Based Structural Equation Modeling (CB-SEM). CB-SEM provides a robust analytical framework capable of simultaneously assessing measurement validity and evaluating direct and indirect mediation pathways, thereby empirically bridging the gap between theoretical knowledge and sustainable action among pre-service chemistry teachers

In filling the empirical, theoretical, and methodological gaps, this study aims to analyze sustainability consciousness *in* prospective chemistry teacher students in Indonesia through structural equation modeling (SEM) based on the multidimensional construct SCQ (Arantes & Sousa, 2025) . specific, research This aim For test: (1) profile multidimensional *Sustainability Consciousness* (Knowingness, Attitudes, and Behaviours*)* of prospective chemistry teachers in Indonesia; (2) influence direct Sustainability Knowingness to Sustainability Attitudes; (3) influence direct Sustainability Attitudes to Sustainability Behaviours*;* and (4) roles mediation Sustainability Attitudes in connection between knowingness and behaviours. Research results are expected to contribute theoretically to strengthening the ESD literature in higher education, while also contributing practically to LPTK in Indonesia by reorienting curriculum-responsive chemistry teacher education to address sustainability in the era of Society 5.0.

METHOD

Research Design

This study employed a quantitative research design with a correlational-causal approach based on Covariance-Based Structural Equation Modeling (CB-SEM) (Hair et al., 2021). CB-SEM was selected as the analytical framework to simultaneously validate the multidimensional measurement model of Sustainability Consciousness (First-Order and Second-Order Confirmatory Factor Analysis) and to evaluate the direct and indirect structural relationship pathways between Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours.

Participants and Ethical Considerations

The research population comprised active pre-service chemistry teachers enrolled in Teacher Training Institutions (LPTKs) across Indonesia. A non-probability sampling technique combining purposive and convenience sampling was utilized. Inclusion criteria required participants to be active students in Chemistry Education study programs who had completed or were currently enrolled in core chemistry courses and chemistry learning strategy modules. A total sample of 106 pre-service chemistry teachers from five distinct LPTKs in Indonesia successfully completed the study. The respondent distribution is detailed in Table 1.

Table 1. Distribution of respondents based on origin college tall

College	n	Percentage (%)
Walisongo State Islamic University Semarang	82	77.35
Semarang State University	8	7.55
Indonesian Education University	6	5.66
Yogyakarta State University	6	5.66
Malang State University	4	3.78
Total	106	100.00

This identical dataset (N = 106) served as the single sample for both the Confirmatory Factor Analysis (CFA) measurement model validation and the subsequent CB-SEM structural model testing. Sample adequacy was confirmed through statistical power analysis using G*Power, which indicated that N = 106 exceeds the minimum threshold required to achieve a statistical power > 0.80 for detecting moderate-to-large effect sizes (f^2) at a 5% significance level in CB-SEM/AMOS estimation (Hair et al., 2021).

Ethical standards were strictly maintained throughout the research process. Prior to data collection, participants received clear explanations regarding the study's objectives, data confidentiality, and voluntary participation. Digital informed consent was explicitly obtained from all respondents. All data were anonymized and stored securely, ensuring that individual responses could not be linked to participant identities.

Research Instruments and Validity Procedures

Data were collected using the Adapted Sustainability Consciousness Questionnaire (SCQ), originally developed by Gericke et al. (2019) and further refined by Arantes and Sousa (2025). The instrument comprises 27 items distributed strictly and proportionally across three main dimensions: Sustainability Knowingness (9 items), Sustainability Attitudes (9 items), and Sustainability Behaviours (9 items). Each dimension incorporates three items dedicated to each of the three pillars of sustainable development: environmental, social, and economic. Responses were recorded using a 5-point Likert scale ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree").

To ensure linguistic and contextual equivalence within the Indonesian chemistry education setting, the SCQ underwent a rigorous forward-backward translation procedure by bilingual experts in science education. Content validity was evaluated and verified by three expert reviewers in Environmental and Chemistry Education.

To address potential self-report limitations and mitigate social desirability bias (Reviewer A, Comment 6), several procedural controls were implemented during instrument design and administration: (1) item wording was carefully crafted to minimize normative framing; (2) complete participant anonymity was emphasised to encourage candid self-assessment; and (3) instructions explicitly reassured respondents that there were no 'right' or 'wrong' answers. Furthermore, construct validity and reliability were empirically evaluated using rigorous statistical parameters during the CFA stage, including standardised factor loadings (ʎ ≥ 0.50), Average Variance Extracted (AVE ≥ 0.50), and Composite Reliability (CR ≥ 0.70) (Hair et al., 2019; 2021).

Data Collection Procedures and Methodological Flowchart

Data collection was conducted digitally via a secure online platform distributed across the five participating LPTKs from March to May 2025. The sequential methodological workflow—spanning participant recruitment, data collection, validation, CB-SEM modeling, and reporting—is illustrated in Figure 1 (Methodological Flowchart).



Figure 1. Methodological Flowchart of the Study

Data Analysis

Data were analyzed using IBM SPSS Statistics (v26) and IBM SPSS AMOS (v26) software8. The analytical procedure followed a two-stage structural equation modeling strategy (Hair et al., 2021)48:

1. Stage 1: Measurement Model Assessment: Descriptive statistics (means, standard deviations, categorizations) were computed using SPSS8more_horiz. Confirmatory Factor Analysis (CFA) was conducted in AMOS to evaluate first-order measurement models68. Convergent validity was assessed based on standardised factor loadings (ʎ ≥ 0.50), Average Variance Extracted (AVE ≥ 0.50), and Composite Reliability (CR ≥ 0.70)68. Discriminant validity was evaluated using the Fornell–Larcker criterion, verifying that the square root of the AVE for each construct exceeded its inter-construct correlations8.
2. Stage 2: Structural Model Assessment: The second-order structural model was evaluated to test hypothesised direct and indirect structural pathways between latent variables1112. Path significance was determined using standardised regression weights (gamma), Critical Ratios (CR ≥ 1.96), and p-values (p < 0.05)11. Overall model fit was evaluated across multiple Goodness-of-Fit (GoF) indices: Chi-square/df (CMIN/df \le 3.00), Comparative Fit Index (CFI ≥ 0.90), Tucker–Lewis Index (TLI ≥ 0.90), Standardised Root Mean Square Residual (SRMR ≤ 0.08), and Root Mean Square Error of Approximation (RMSEA ≤ 0.08) (Byrne, 2016; Hair et al., 2019)11more_horiz. Coefficients of determination (R^2 / Squared Multiple Correlations) were evaluated to quantify variance explained in endogenous constructs

RESULT

Respondent Demographic Profile

Data were collected from 106 active pre-service chemistry teachers across five Teacher Training Institutions (LPTKs) in Indonesia. A summary of participant demographic characteristics is presented in Table 2.

Table 2. Demographic Profile of Respondents (N = 106)

Characteristics Demographics	Category	Frequency (n)	Percentage (%)
Gender	Woman	84	79.20
	Man	22	20.80
Total		106	100.00

As shown in Table 2, female students represented the majority of respondents (79.20%, n = 84), while male students accounted for 20.80% (n = 22). This distribution accurately reflects the gender demographic profile typically observed in chemistry education undergraduate programs across Indonesian teacher training institutions.

The demographic profile provides an overview of the participants whose responses were used to examine Sustainability Consciousness among pre-service chemistry teachers. Because the sample consisted of students from five LPTKs, the findings reflect responses collected across multiple institutional contexts. However, the distribution of respondents across institutions was not equal, as most participants came from Walisongo State Islamic University Semarang. Therefore, the demographic results should be interpreted in relation to the composition of the sample rather than as a nationally representative profile of all pre-service chemistry teachers in Indonesia.

Analysis of Descriptive *Sustainability Consciousness*

Descriptive statistical analyses were conducted to map the baseline profiles across the three core dimensions of Sustainability Consciousness: Sustainability Knowingness (K), Sustainability Attitudes (A), and Sustainability Behaviours (B) across environmental, social, and economic pillars. The descriptive results are summarised in Table 3.

As detailed in Table 3, the Sustainability Knowingness dimension achieved the highest overall score (Mean = 4.30, Very High), with high scores observed across environmental (4.30), social (4.35), and economic (4.26) subdimensions. Similarly, Sustainability Attitudes recorded a very high overall mean (Mean = 4.21). Conversely, Sustainability Behaviours yielded a lower overall score (Mean = 3.96, High),

with the economic behaviour subdimension recording the lowest score (Mean = 3.60). This pattern illustrates a descriptive gap between cognitive comprehension and actionable practices.

A closer examination of the three dimensions reveals that the social dimension consistently obtained relatively high mean scores. Social Knowingness and Social Attitudes both recorded a mean of 4.35, while Social Behaviours reached 4.34. These results indicate that respondents reported relatively strong sustainability-related understanding, attitudes, and behaviours in the social domain. Nevertheless, because the data were obtained through a self-report questionnaire, these scores reflect participants' reported responses and should not be interpreted as direct observations of their actual behaviour.

Table 3. Recapitulation Analysis Descriptive Dimensions *Sustainability Consciousness*

Latent Variables	Dimensions	Mean Score	Category	Average Variables	Category Overall
Sustainability Knowingness (K)	Environmental (ENV)	4.30	Very high	4.30	Very high
	Social (SOC)	4.35	Very high		
	Economic (ECO)	4.26	Very high		
Sustainability Attitudes (A)	Environmental (ENV)	4.03	High	4.21	Very high
	Social (SOC)	4.35	Very high		
	Economic (ECO)	4.25	Very high		
Sustainability Behaviours (B)	Environmental (ENV)	3.95	High	3.96	High
	Social (SOC)	4.34	Very high		
	Economic (ECO)	3.60	High		

Note: The category interval ranges on the five-point Likert scale are 1.00–1.80 (Very Low), 1.81–2.60 (Low), 2.61–3.40 (Moderate), 3.41–4.20 (High), and 4.21–5.00 (Very High).

The environmental dimension showed a different pattern. Environmental Knowingness obtained a mean score of 4.30, whereas Environmental Attitudes and Environmental Behaviours recorded mean score of 4.03 and 3.95, respectively. Although all three scores fell within the High or Very High categories, the lower mean score for attitudes and behaviours indicates that the three dimensions did not have identical descriptive profiles. A similar, more pronounced difference was observed in the economic dimension, where Knowingness and Attitudes obtained mean scores of 4.26 and 4.25, respectively, while Behaviours recorded a mean of 3.60.

These descriptive findings suggest that positive sustainability-related knowledge and attitudes were accompanied by comparatively lower reported behaviour, particularly in the economic domain. However, differences between mean scores alone do not establish a statistically significant relationship or causal effect between the dimensions. Instead, they provide an initial descriptive basis for examining the multidimensional measurement model and identifying areas that warrant further investigation in the subsequent CFA and structural model assessments.

Evaluation *of* the Measurement Model through *Confirmatory Factor Analysis* (CFA)

Evaluation of the measurement model was done using Confirmatory Factor Analysis (CFA) on first-order constructs for test validity and reliability of the Sustainability Consciousness Questionnaire (SCQ). Based on the recommendations of Hair et al. (2019), an indicator is declared to meet convergent validity if it has a standardized factor loading (λ) value ≥ 0.50 and is statistically significant ($p < 0.05$). In addition, construct reliability is evaluated using the Composite Reliability value (CR ≥ 0.70), while convergent validity is strengthened through the Average Variance Extracted (AVE ≥ 0.50) value.

The results of the initial measurement model evaluation showed that two indicators that did not meet the convergent validity criteria, namely AL1 in the Environmental Attitudes dimension and BE2 in the Economic Behaviours dimension. The AL1 indicator had a *standardised factor loading value* of -0.085 with a *p value* = 0.723, while the BE2 indicator had a *loading factor value* of 0.234 with a *p value* = 0.162. In addition to being statistically insignificant, the BE2 indicator also gave rise to an anomaly in the form of

a negative variance (Heywood case*)* in the error variance (error variance e11). Therefore, these two indicators were eliminated from the model, following Hair et al. (2019), to obtain a more stable measurement model and to meet the SEM assumptions.

After eliminating indicators AL1 and BE2, all error variances returned to positive values, thus successfully resolving the *Heywood case problem*. The final measurement model consisted of 25 indicators that met all validity and reliability criteria. The CFA test results after the elimination process are presented in Table 4.

Table 4. CFA Test Results, Validity, and Reliability of *Post-* Item Elimination Constructs

Main Construct	Indicator Dimensions	Valid Items	Item Eliminated	Standardised Loading (λ)	Composite Reliability (CR)	Average Variance Extracted (AVE)	Status
Knowingness (KSUS)	Environmental (Kenv)	KL1, KL2, KL3	–	0.72–0.84	0.83	0.62	Valid & Reliable
	Social (Ksoc)	KS1, KS2, KS3	–	0.75–0.88	0.85	0.66	Valid & Reliable
	Economic (Keco)	KE1, KE2, KE3	–	0.71–0.82	0.82	0.60	Valid & Reliable
Attitudes (ASUS)	Environmental (Aenv)	AL2, AL3	AL1	0.70–0.81	0.78	0.55	Valid & Reliable
	Social (Asoc)	AS1, AS2, AS3	–	0.74–0.86	0.84	0.64	Valid & Reliable
	Economic (Aeco)	AE1, AE2, AE3	–	0.70–0.85	0.83	0.62	Valid & Reliable
Behaviours (BSUS)	Environmental (Benv)	BL1, BL2, BL3	–	0.65–0.79	0.78	0.54	Valid & Reliable
	Social (BSoc)	BS1, BS2, BS3	–	0.73–0.87	0.84	0.64	Valid & Reliable
	Economic (Beco)	BE1, BE3	BE2	0.62–0.76	0.74	0.50	Valid & Reliable

Based on Table 4, all retained indicators have standardised factor loadings ≥ 0.50 and are significant at $p < 0.001$. In addition, all constructs show Composite Reliability *values* ranging from 0.74–0.85 and Average Variance Extracted values between 0.50–0.66, thus meeting the reliability and convergent validity criteria. Thus, the measurement model is declared suitable to proceed to the structural model evaluation stage.

The removal of AL1 and BE2 also indicates that not all questionnaire indicators performed equally well among Indonesian pre-service chemistry teachers. In particular, the initial results for BE2 indicated that its relationship with the intended economic behaviour construct was weak and statistically nonsignificant. This finding warrants attention because the economic behaviour dimension also had the lowest descriptive mean among the three sustainability domains. Nevertheless, the statistical performance of an individual indicator should be distinguished from the overall descriptive level of a dimension. The removal of BE2 was based on the measurement model results and should not, by itself, be interpreted as proof that respondents did not engage in the corresponding behaviour.

Taken together, the results indicate that the retained indicators demonstrated acceptable reliability and convergent validity according to the criteria applied in this study. The measurement model was therefore considered suitable for subsequent assessment of the higher-order structure of Sustainability Consciousness. However, these findings primarily establish the measurement properties of the retained indicators; they do not independently establish causal relationships among Knowingness, Attitudes, and Behaviours.

Model Respecification and Evaluation Process *Goodness-of-Fit*

After the measurement model fulfil criteria for validity and reliability, the evaluation to structural model suitability order second (second-order structural model*)* uses various index goodness *-of-fit* evaluation done in a way gradually through three stages, namely the initial model, the *model* after elimination AL1 and BE2 indicators, as well as the final model after *the* respecification process based on *Modification Indices* (MI).

The respecification process was conducted to improve the model's suitability to the empirical data without changing the conceptual structure of the study. In accordance with Byrne's (2016) recommendation, the addition of correlations between residuals is only done if it has an adequate theoretical basis. Based on the *Modification Indices value,* two pairs of residuals that meet this criterion are e6 ↔ e10 (MI = 15.863) which connects indicators AE3 and BE3, and e29 ↔ e16 (MI = 15.424) which connects indicators KL2 and BS1. The addition of these two correlations was carried out because the indicators involved share a close conceptual context, thereby justifying their inclusion theoretically. Goodness-of-fit values at each stage of model respecification are presented in Table 5.

Table 5. Comparison of *Goodness-of-Fit* Index at Each Stage of Model Respecification

Index *Goodness-of-Fit*	Early Model	Post Item Elimination	Final Model	Cut-off Value	Final Evaluation
Chi-Square (χ^2)	628,636	548,818	513,578	The smaller the better	Fit
Degree of Freedom (df)	320	271	269	–	–
CMIN/DF	1,964	2,025	1,909	≤ 2.00 (or ≤ 3.00)	Good Fit
GFI	0.707	0.721	0.739	≥ 0.90	Marginal Fit
AGFI	0.665	0.665	0.684	≥ 0.90	Marginal Fit
CFI	0.839	0.852	0.870	≥ 0.90	Marginal Fit
TLI	0.823	0.837	0.855	≥ 0.90	Marginal Fit
NFI	0.749	0.749	0.765	≥ 0.90	Marginal Fit
RMSEA	0.096	0.062	0.059	≤ 0.08	Good Fit

As shown in Table 5, the respecification process resulted in a gradual improvement in model fit. The Chi-Square value decreased from 628.636 in the initial model to 513.578 in the final model. Improvements were also observed in the CMIN/DF value, which decreased to 1.909, thereby meeting the good-fit criteria. Furthermore, the RMSEA value was successfully reduced from 0.096 in the initial model to 0.059 in the final model, indicating a low level *of* approximation error and indicating that the model has a good fit with the empirical data.

Although some incremental fit indices*,* such as CFI (0.870), TLI (0.855), GFI (0.739), AGFI (0.684), and NFI (0.765) are still in the marginal fit category*,* the combination of CMIN/DF = 1.909 and RMSEA = 0.059 has met the main criteria for SEM model evaluation. Therefore, the final structural model can be declared as acceptable *fit* and meets the requirements for use in the analysis stage of relationships between constructs and hypothesis testing (Byrne, 2016; Hair *et al.*, 2019; Hooper *et al.*, 2008).

Structural *Model* and Path Coefficients

After the model meets the requirements criteria goodness-of- fit analysis continued with the evaluation of the structural model order second (second-order structural model) for identify the contribution of each latent construct to formation Sustainability Consciousness. Structure hierarchical model that consists of on construct order second (Sustainability Consciousness) and third construct order first, namely Knowingness (KSUS), Attitudes (ASUS), and Behaviours (BSUS), along with nine its subdimensions, presented in Figure 1.

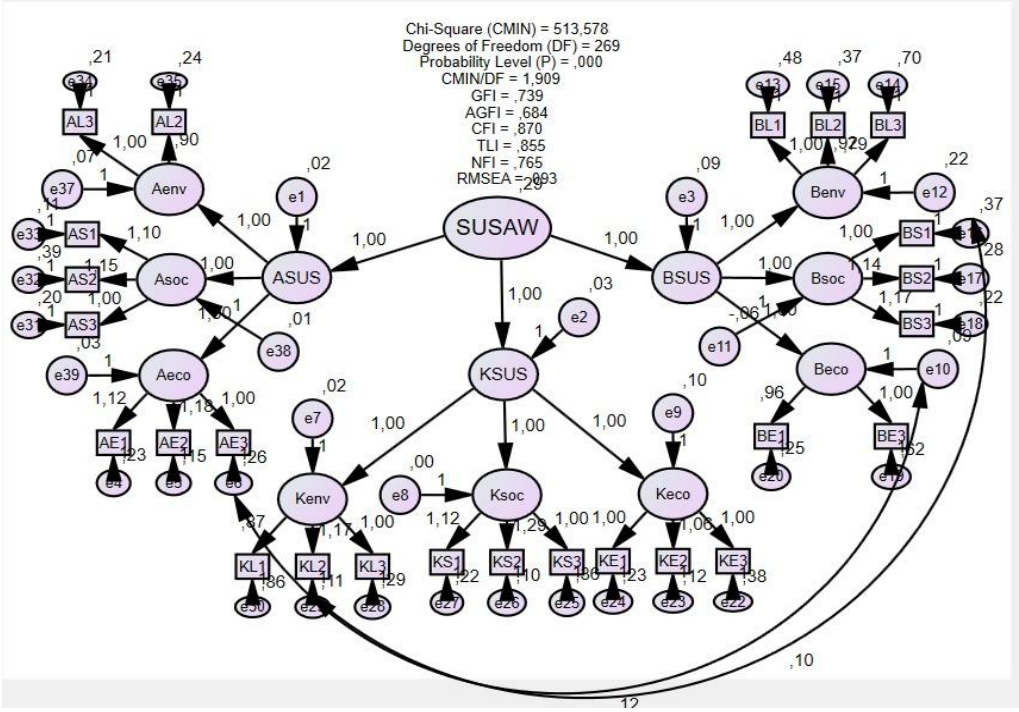


Figure 2. Path Diagram of the Second-Order Model of Sustainability Consciousness

Figure 2 shows that construct Sustainability Consciousness (SUSAW) reflected by three construct order first, namely Knowingness (KSUS), Attitudes (ASUS), and Behaviours (BSUS). Each construct is further reflected by three subdimensions, namely environmental, social, and economic, so that the form is a hierarchical second-order CFA. The magnitude of the contribution of each structural relationship is presented in Table 6.

Based on Table 6, the first three constructs are shown to significantly reflect Sustainability Consciousness. The Knowingness construct (KSUS) provides the greatest contribution to the formation of Sustainability Consciousness with a standardized coefficient of 0.951, followed by Attitudes (ASUS) of 0.924, while Behaviours (BSUS) provides a relatively lower contribution with a coefficient of 0.782. All of these relationships are significant at the $p < 0.001$ level, indicating that the three dimensions are the main components forming the construct of Sustainability Consciousness.

At the first-order construct level, all subdimensions showed a significant relationship to their parent construct, except for the BSUS → Beco path. This path has a negative standard coefficient ($\gamma = -0.058$), a Critical Ratio (CR) value = −0.714, and $p = 0.475$, making it statistically insignificant. This finding indicates that the Economic Behaviours dimension has not been able to adequately reflected the Behaviours construct in the context of the chemistry teacher candidates who were the research respondents. Overall, the results of the structural model analysis indicate that the Knowingness and Attitudes constructs are the most dominant dimensions in forming Sustainability Consciousness, while the Economic Behaviours dimension still requires further attention as it has not provided a significant contribution to the sustainability behaviour construct.

Table 6. Path Coefficients *of the* Structural Model

Structural Path	Unstandardised Estimate (β)	Standardised Estimate (γ)	SE	CR	p-value	Information
SUSAW → ASUS	1,000	0.924	Fixed	Fixed	***	Significant
SUSAW → KSUS	1,000	0.951	0.112	8,928	***	Significant
SUSAW → BSUS	1,000	0.782	0.145	6,896	***	Significant
KSUS → Kenv	1,000	0.812	Fixed	Fixed	***	Significant
KSUS → Ksoc	1,000	0.895	0.108	9,259	***	Significant
KSUS → Keco	1,000	0.841	0.115	8,695	***	Significant
ASUS → Aenv	1,000	0.765	Fixed	Fixed	***	Significant
ASUS → Asoc	1,000	0.882	0.121	8,264	***	Significant
ASUS → Aeco	1,000	0.830	0.118	8,474	***	Significant
BSUS → Benv	1,000	0.741	Fixed	Fixed	***	Significant
BSUS → Bsoc	1,000	0.853	0.132	7,575	***	Significant
BSUS → Beco	-0.060	-0.058	0.084	-0.714	0.475	No significant

*Note: *** indicates significance at p < 0.001 level.*

DISCUSSION

Profile Multidimensional Sustainability Consciousness of Prospective Chemistry Teachers in Indonesia

The research results show that Sustainability Consciousness (SC) among Indonesian pre-service chemistry teachers is a multidimensional construct consisting of three main dimensions: Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours, which encompass environmental, social, and economic aspects. The results of the second-order confirmatory factor analysis indicate that these three dimensions are related to the higher-order construct of Sustainability Consciousness. The final model demonstrated an acceptable fit, with CMIN/DF = 1.909 and RMSEA = 0.059, although several incremental fit indices remained below the recommended threshold of 0.90. Therefore, the model provides support for the proposed multidimensional structure, while its overall fit should be interpreted with appropriate caution.

Descriptively, the three dimensions showed different patterns. Sustainability Knowingness had the highest overall mean score (M = 4.30), followed by Sustainability Attitudes (M = 4.21), whereas Sustainability Behaviours had the lowest overall mean (M = 3.96). This pattern indicates that respondents reported very high levels of sustainability-related knowledge and attitudes, while their reported behaviours were comparatively lower. Although the differences between these mean scores do not establish causal relationships, they highlight a descriptive distinction between understanding sustainability issues, expressing positive attitudes toward them, and reporting corresponding practices.

These findings are consistent with the framework of the Sustainability Consciousness Questionnaire (SCQ) developed by Gericke et al. (2019) and subsequently examined by Arantes and Sousa (2025), which conceptualizes Sustainability Consciousness in terms of knowingness, attitudes, and behaviours. The present results extend the discussion to Indonesian pre-service chemistry teachers by

examining these dimensions across environmental, social, and economic domains. The findings also demonstrate why sustainability should not be assessed solely through knowledge-related indicators. A comprehensive understanding requires consideration of the affective and behavioural dimensions alongside cognitive understanding.

The social domain showed relatively high mean scores across all three dimensions. Social Knowingness and Social Attitudes each obtained a mean score of 4.35, while Social Behaviours recorded a mean of 4.34. This consistency suggests that respondents reported strong sustainability-related orientations in the social domain. Such a pattern may reflect the relevance of social concerns, including social responsibility and the welfare of others, to respondents' understanding of sustainable development. However, the present study did not directly investigate the sources of these responses; consequently, possible explanations regarding educational experiences, social norms, or personal values should be treated as interpretations that require further investigation.

The environmental domain showed a different descriptive pattern. Environmental Knowingness had a mean score of 4.30, while Environmental Attitudes and Environmental Behaviours obtained mean scores of 4.03 and 3.95, respectively. Although these scores remained within the High or Very High categories, the lower means for attitudes and behaviours indicate that respondents' reported environmental practices did not correspond exactly to their reported knowledge. This distinction is relevant to chemistry education because understanding environmental processes does not necessarily mean that students consistently apply environmentally responsible practices in their everyday lives.

The differences were more pronounced in the economic domain. Economic Knowingness and Economic Attitudes obtained mean scores of 4.26 and 4.25, respectively, whereas Economic Behaviours recorded a mean of 3.60. Although the latter remained within the High category according to the classification used in this study, it has the lowest mean across the nine subdimensions. This finding suggests that economic sustainability practices may be a relevant area for further attention in pre-service chemistry teacher education. It should not, however, be interpreted as evidence that respondents generally lacked sustainable economic behaviour, because the mean remained above the midpoint of the five-point scale and the data were self-reported.

The differences between the three domains highlight the multidimensional nature of Sustainability Consciousness. Environmental, social, and economic sustainability are interconnected, but they may be expressed differently in respondents' reported knowledge, attitudes, and behaviours. In chemistry education, these dimensions can be connected through issues such as chemical waste management, responsible material consumption, access to resources, and the environmental and social consequences of industrial production. Integrating such contexts into teacher education may help prospective chemistry teachers consider sustainability as an interconnected system rather than as an exclusively environmental issue (Mahaffy et al., 2020; Matlin et al., 2021).

Overall, the descriptive findings and second-order measurement results support the examination of Sustainability Consciousness as a construct encompassing cognitive, affective, and behavioural dimensions. At the same time, the differences in mean scores indicate that these dimensions should not be assumed to be equivalent in their reported levels. Further research is needed to determine how educational experiences and contextual conditions relate to these differences and whether they predict observable sustainability-related practices.

Relationship between Sustainability Knowingness and Sustainability Attitudes

The relationship between Sustainability Knowingness and Sustainability Attitudes is an important theoretical consideration in understanding how sustainability-related understanding and evaluations may be connected. Knowingness represents an individual's understanding of sustainability issues, whereas attitudes concern their evaluations and dispositions toward those issues. In educational contexts, knowledge can provide a foundation for evaluating environmental, social, and economic challenges. Nevertheless, a theoretical relationship between these dimensions should be distinguished from an empirically demonstrated direct effect.

The results of the present study showed high mean scores for both Sustainability Knowingness (M = 4.30) and Sustainability Attitudes (M = 4.21). At the second-order measurement level, Knowingness and Attitudes were both strongly associated with the higher-order Sustainability Consciousness construct,

with standardized coefficients of 0.951 and 0.924, respectively. These coefficients indicate the strength of the relationships between the higher-order construct and its corresponding dimensions within the specified measurement model. They do not, however, represent a direct path from Knowingness to Attitudes.

Accordingly, the current results support the relevance of both Knowingness and Attitudes as dimensions of Sustainability Consciousness, but they do not establish that higher Knowingness directly leads to more positive Attitudes among respondents. Testing that proposition requires a structural model in which Sustainability Knowingness is explicitly specified as a predictor of Sustainability Attitudes and the corresponding path coefficient, standard error, critical ratio, and p-value are reported.

Theoretically, sustainability knowledge may help prospective chemistry teachers recognise the implications of chemical production, consumption, and waste management for environmental quality and human well-being. An understanding of green chemistry, resource efficiency, and the broader consequences of chemical processes can provide a basis for evaluating sustainability-related decisions. In this context, the integration of sustainability issues into chemistry education may help students connect scientific concepts with environmental and social responsibilities (Akaygun & Aslan-Tutak, 2021; Mahaffy et al., 2020).

Previous work has emphasised the importance of sustainability-related understanding and educational experiences in developing orientations toward sustainable development. UNESCO (2020) identifies education as an important component of the transition toward sustainability, while Nousheen et al. (2022) examine sustainability-related orientations among pre-service teachers. These perspectives provide a theoretical basis for considering the relationship between knowingness and attitudes in teacher education. Nevertheless, the present study's descriptive means and second-order coefficients should not be treated as a direct replication of a causal relationship unless the corresponding structural path has been estimated.

For Indonesian Teacher Training Institutions (LPTKs), the results suggest that sustainability-related knowledge and attitudes should both be considered when evaluating prospective chemistry teachers' Sustainability Consciousness. Chemistry courses can connect conceptual learning with environmental, social, and economic issues through green chemistry, socio-scientific issues, and systems thinking. Such approaches may help students evaluate the consequences of scientific and technological decisions in authentic contexts (Eilks, 2021; Mahaffy et al., 2020). However, whether these approaches produce measurable changes in attitudes or behaviours requires direct evaluation through appropriately designed educational research.

Thus, the findings highlight the importance of Knowingness and Attitudes within the multidimensional construct of Sustainability Consciousness. They also identify a direction for future research: explicitly testing the direct relationship between these dimensions and determining whether the relationship remains significant after relevant contextual variables are considered.

Sustainability Attitudes, Sustainability Behaviours, and the Economic Behaviour Dimension

The relationship between sustainability-related attitudes and behaviours is an important issue in sustainability education because positive evaluations of sustainable development do not necessarily translate into consistent practices. The descriptive results of this study showed that Sustainability Attitudes had a very high overall mean (M = 4.21), whereas Sustainability Behaviours had a lower mean (M = 3.96). A similar difference was observed in the economic domain, where Economic Attitudes had a mean score of 4.25 and Economic Behaviours had a mean score of 3.60. These findings indicate a descriptive difference between reported attitudes and behaviours, particularly in the economic domain.

The second-order measurement model provides additional information about the relationships between the behavioural subdimensions and the higher-order Sustainability Behaviours construct. Environmental Behaviours had a standardized coefficient of 0.741, and Social Behaviours had a coefficient of 0.853; both were statistically significant at $p < 0.001$. In contrast, the coefficient for Economic Behaviours was −0.058 and was not statistically significant ($p = 0.475$). This result indicates that Economic Behaviours did not demonstrate a statistically significant relationship with the higher-order Behaviours construct under the specified model.

This finding should be interpreted carefully. The nonsignificant coefficient does not demonstrate that sustainability attitudes have no influence on economic behaviour. Rather, it indicates that the economic behavioural dimension did not contribute significantly to the higher-order measurement construct in the current model. Establishing whether Sustainability Attitudes predict Sustainability Behaviours would require a separate structural analysis that explicitly estimates the Attitudes → Behaviours path. Therefore, the current results provide evidence of a difference in the measurement pattern across behavioural domains, not evidence of a statistically confirmed causal relationship between attitudes and behaviours.

One possible area for further examination is the nature of the economic behaviour indicators. The relatively low descriptive mean for Economic Behaviours, together with the nonsignificant second-order coefficient, suggests that the economic dimension may not function in the same way as the environmental and social dimensions within this sample. The initial CFA also identified BE2 as an indicator with a low, statistically nonsignificant loading and a negative error variance. Although BE2 was removed and the retained indicators subsequently met the specified first-order loading, CR, and AVE criteria, the second-order relationship between Economic Behaviours and Sustainability Behaviours remained nonsignificant. These findings warrant additional examination of the content and contextual relevance of the economic behaviour indicators among Indonesian pre-service chemistry teachers.

The descriptive results also identified a comparatively low score on an item related to purchasing or reusing second-hand goods, referred to in the original manuscript as *thrifting*. This item-level result may provide a useful illustration of one aspect of economic sustainability, but it should be distinguished from the overall mean for Economic Behaviours. The item-level score and the dimension-level mean represent different levels of analysis and should not be used interchangeably. Moreover, any interpretation of the item should be grounded in its exact wording and the corresponding item-level results.

The observed difference between sustainability attitudes and reported behaviours is consistent with broader discussions of the value–action gap in sustainability education. Burmeister and Eilks (2013) and Eilks (2021) emphasised the importance of connecting sustainability understanding with opportunities for meaningful action in science education. Marcos-Merino et al. (2023) and Olsson et al. (2022) also discussed the relevance of contextual and psychological conditions in understanding sustainability-related behaviour. These studies provide a useful theoretical background for interpreting the present descriptive pattern, although they do not establish the specific causes of the economic behaviour results observed in this sample.

Economic sustainability practices may be influenced by several conditions, including personal resources, access to affordable alternatives, consumption habits, social expectations, and the availability of reuse or recycling facilities. For example, choosing a reused product may depend not only on an individual's environmental or economic attitudes but also on the availability, quality, price, and social acceptability of that product. Similarly, sustainable consumption decisions may be shaped by household circumstances and local opportunities. These factors are plausible explanations for further research; they were not directly measured in the present study and therefore cannot be identified as the causes of the observed results.

In chemistry teacher education, the economic dimension can be explored through authentic contexts such as material efficiency, waste minimization, the circular economy, and the economic consequences of chemical production and consumption. These topics can help prospective teachers consider how scientific and technological decisions interact with environmental protection and social welfare. Green chemistry and socio-scientific issues may provide useful pedagogical contexts for connecting chemical knowledge with broader sustainability challenges (Akaygun & Aslan-Tutak, 2021; Mahaffy et al., 2020; Matlin et al., 2021).

Overall, the results highlight the need to examine the environmental, social, and economic dimensions of Sustainability Behaviours separately as well as within the broader construct of Sustainability Consciousness. The significant coefficients for environmental and social behaviours, alongside the nonsignificant coefficient for economic behaviours, indicate that the three domains did not show identical measurement relationships in this sample. Future research should investigate whether this

pattern is associated with indicator characteristics, contextual differences, or other factors that may influence reported economic sustainability practices.

The Potential Role of Sustainability Attitudes in the Relationship between Knowingness and Behaviours

The relationship between Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours can be understood through the multidimensional framework of Sustainability Consciousness, which conceptualizes sustainability-related cognition, affect, and action as interconnected components of individuals' orientations toward sustainable development (Gericke et al., 2019). Within this framework, Knowingness represents an individual's understanding of sustainability issues, Attitudes reflect their evaluations and dispositions toward sustainability, and Behaviours concern the extent to which these orientations are expressed through reported everyday practices. Although these dimensions are conceptually related, their interrelationship does not necessarily imply that greater knowledge automatically produces sustainable behaviour.

The findings of this study reveal descriptive differences between Knowingness, Attitudes, and Behaviours among Indonesian pre-service chemistry teachers. Sustainability Knowingness obtained a mean score of 4.30, followed by Sustainability Attitudes (M = 4.21) and Sustainability Behaviours (M = 3.96). This pattern suggests that strong reported understanding and positive sustainability orientations were not accompanied by equally high reported behavioural scores. Similar concerns have been raised in sustainability education, where researchers emphasise the importance of connecting conceptual understanding with opportunities for meaningful action (Burmeister & Eilks, 2013; Eilks, 2021). In chemistry teacher education, this connection is particularly important because prospective teachers need to understand sustainability principles and develop the capacity to apply them when addressing environmental, social, and economic challenges (Akaygun & Aslan-Tutak, 2021; Jegstad & Koballa, 2014).

Nevertheless, the role of Sustainability Attitudes as a mediating mechanism requires careful interpretation. Although attitudes are conceptually positioned between knowingness and behaviours in the proposed theoretical explanation, establishing an empirical mediation effect requires statistical evidence of the indirect relationship between these constructs. The second-order measurement model reported in this study supports the multidimensional nature of Sustainability Consciousness and identifies differences in the descriptive levels and measurement relationships of its constituent dimensions. However, these findings alone do not establish that Attitudes significantly mediate the relationship between Knowingness and Behaviours.

To test the proposed mediation mechanism, a separate structural model would need to specify the direct path from Knowingness to Attitudes, the direct path from Attitudes to Behaviours, and the direct path from Knowingness to Behaviours where theoretically appropriate. The indirect effect through Attitudes would then need to be estimated and evaluated using an appropriate inferential procedure, such as bootstrapping, with its estimate and confidence interval reported. Without these results, the mediation mechanism should be presented as a theoretical proposition rather than an empirically confirmed finding of the current model.

The differences across the environmental, social, and economic domains further illustrate the complexity of translating sustainability orientations into action. The descriptive results indicate that Economic Knowingness (M = 4.26) and Economic Attitudes (M = 4.25) were very high, whereas Economic Behaviours obtained a lower mean score of 3.60. Moreover, the second-order measurement model showed that the relationship between Economic Behaviours and the higher-order Sustainability Behaviours construct was negative and statistically nonsignificant (standardized coefficient = −0.058, p = 0.475). This finding should not be interpreted as proof that positive economic attitudes have no influence on behaviour; rather, it indicates that the economic behavioural dimension did not demonstrate a statistically significant contribution to the behavioural construct within the specified model.

This descriptive pattern is consistent with broader discussions of the value–action gap in sustainability education, in which individuals' favourable orientations toward sustainability do not necessarily translate into corresponding practices. Marcos-Merino et al. (2023) and Olsson et al. (2022) emphasize the importance of examining contextual and psychological conditions when explaining sustainability-related behaviour. Arantes and Sousa (2025) also highlight the relevance of circular economy practices in examining Sustainability Consciousness. In the present study, the comparatively

lower score for purchasing or reusing second-hand goods suggests that economic sustainability practices may be less consistently reported than respondents' stated knowledge and attitudes would imply. However, because the study relied on self-reported questionnaire data, this interpretation should remain cautious and should not be treated as direct evidence of respondents' actual purchasing decisions.

From a theoretical perspective, these findings reinforce the importance of distinguishing cognitive, affective, and behavioural dimensions when examining Sustainability Consciousness. Gericke et al. (2019) established the SCQ as a multidimensional instrument for assessing sustainability-related knowingness, attitudes, and behaviours, while Arantes and Sousa (2025) further examined its structural validity across educational contexts. The present findings contribute to this discussion by examining the multidimensional construct among Indonesian pre-service chemistry teachers and showing that the three domains do not necessarily exhibit equivalent descriptive levels or measurement relationships. In particular, the nonsignificant relationship between Economic Behaviours and the higher-order Behaviours construct highlights the need to examine whether the economic behaviour indicators adequately represent this domain in the present population.

The model respecification results also require consideration. Correlations between selected residuals were introduced to improve model fit based on the Modification Indices and the conceptual proximity of the associated indicators. Although these correlations may indicate shared variance not fully explained by the specified model, they cannot independently identify the underlying causes of that shared variance. Social norms, campus culture, socioeconomic circumstances, and access to sustainable consumption alternatives are plausible factors for future investigation rather than established explanations for the present findings. Subsequent studies could explicitly incorporate these variables to examine whether they are associated with the relationships among knowingness, attitudes, and behaviours.

These findings have practical implications for chemistry teacher education in Indonesian Teacher Training Institutions (LPTKs). Consistent with Education for Sustainable Development principles (UNESCO, 2020), sustainability learning should extend beyond theoretical understanding to include contextualised learning experiences that connect chemistry concepts with authentic sustainability challenges. Approaches integrating green chemistry, socio-scientific issues, and systems thinking may help prospective teachers examine the environmental, social, and economic consequences of chemical production and consumption (Akaygun & Aslan-Tutak, 2021; Mahaffy et al., 2020). For example, projects involving chemical waste management, responsible consumption, material efficiency, and circular economy practices could provide opportunities to apply sustainability knowledge in practical contexts.

Institutional support is also important in creating opportunities for sustainable action. LPTKs could strengthen sustainability-oriented learning through accessible waste-management facilities, reuse initiatives, and campus projects that encourage responsible resource consumption. These initiatives should be understood as potential educational and institutional strategies whose effectiveness requires further evaluation, rather than interventions directly tested by this study. By combining conceptual learning with authentic opportunities for action, chemistry teacher education may better support the development of sustainability competencies among prospective teachers.

In summary, the present study provides evidence that Sustainability Consciousness among Indonesian pre-service chemistry teachers can be examined through the related dimensions of knowingness, attitudes, and behaviours, while also revealing descriptive differences and variation in the measurement relationships across sustainability domains. The results particularly highlight the need to investigate economic behaviour more closely. Further structural analyses are required to determine whether Knowingness predicts Attitudes, whether Attitudes predict Behaviours, and whether Attitudes mediate the relationship between Knowingness and Behaviours. Establishing these relationships would provide a more direct empirical basis for explaining how sustainability-related understanding may be translated into reported practices.

Limitations and Recommendations

This study has several limitations. First, the sample comprised 106 pre-service chemistry teachers from five Indonesian teacher education institutions (LPTKs). Although the findings provide insights into Sustainability Consciousness among this population, their generalizability to other teacher

education programs, academic disciplines, and institutional contexts remains limited. Future research should therefore involve larger and more diverse samples from a broader range of teacher education institutions and academic disciplines to improve the representativeness of the findings.

Second, Sustainability Behaviours were measured using a self-reported questionnaire, which may be affected by social desirability bias and discrepancies between reported and actual practices. Future studies could address this limitation by combining questionnaire data with complementary methods, such as behavioural observations, consumption records, or campus environmental audits, to obtain a more comprehensive assessment of sustainability practices.

Third, the study did not comprehensively examine contextual variables, including socioeconomic circumstances, cultural background, and institutional support, that may influence sustainable behaviour. Further research should investigate these factors alongside individual-level variables, such as self-efficacy and social norms, as well as institutional factors, such as campus culture. Examining these variables may help explain why sustainability knowledge and attitudes do not always translate into consistent environmental, social, and economic behaviours.

Finally, although the conceptual framework positions Sustainability Attitudes as a potential mechanism linking Sustainability Knowingness and Sustainability Behaviours, the mediation effect requires explicit statistical testing before such a relationship can be empirically established. Future studies should therefore test the direct and indirect effects within the proposed structural model using appropriate mediation analysis. Longitudinal or other theoretically justified research designs could also help clarify the relationships among Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours over time. These approaches would provide a stronger empirical basis for understanding the conditions under which sustainability knowledge and attitudes are translated into consistent sustainable practices.

CONCLUSION

This study examined Sustainability Consciousness among Indonesian pre-service chemistry teachers using a multidimensional framework comprising Sustainability Knowingness, Sustainability Attitudes, and Sustainability Behaviours across environmental, social, and economic dimensions. The descriptive findings showed that Sustainability Knowingness had the highest mean score (M = 4.30), followed by Sustainability Attitudes (M = 4.21) and Sustainability Behaviours (M = 3.96). This pattern suggests a difference between participants' reported sustainability-related knowledge and attitudes and their reported behaviours.

The confirmatory analysis supported aspects of the proposed multidimensional structure. The final model produced a CMIN/DF value of 1.909 and an RMSEA value of 0.059, although several other fit indices remained below commonly applied thresholds. The results should therefore be interpreted as providing partial support for the proposed model rather than conclusive evidence of uniformly good model fit. The analysis also identified a negative and statistically nonsignificant coefficient for the economic behaviour dimension ($\gamma = -0.058$, $p = 0.475$), highlighting the need to investigate how economic sustainability behaviours are represented and expressed among pre-service chemistry teachers.

These findings underline the importance of chemistry teacher education that connects sustainability knowledge and attitudes with opportunities for meaningful action. Contextualised learning involving green chemistry, socio-scientific issues, responsible consumption, and waste management may provide relevant opportunities for such integration, although the effectiveness of these approaches requires further empirical evaluation. The study is limited by its sample size and composition, its reliance on self-reported data, and aspects of model fit that require further validation. Future research should use larger and more diverse samples, combine questionnaire data with other forms of evidence, and explicitly test structural and indirect relationships before drawing conclusions about the processes linking sustainability knowledge, attitudes, and behaviours.

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AI USE STATEMENT

Google NotebookLM was used to support the organization and review of relevant literature, while Google Gemini was used to assist in creating figures for the manuscript. The authors reviewed and verified all AI-assisted outputs and take full responsibility for the accuracy, interpretation, and final content of the manuscript.

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