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Integrating Sustainability Learning in Thai Higher Education: Impacts on Graduate Students' Knowledge, Attitudes, and Engagement

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ABSTRACT

This study examined how integrating sustainability learning (Sustainability Learning Integration (SLI)) into graduate-level courses affects students' sustainability knowledge, attitudes, and engagement in Thai higher education. The research utilized a mixed-methods Sequential Explanatory Design with the quantitative data gathered from 520 graduate students across six Thai universities. Student opinions were then obtained from validated scales on SLI, Student Sustainability Knowledge (SSK), Student Sustainability Attitudes (SSA), and student engagement. Structural Equation Modeling (SEM) was employed to examine the hypothesized relationships. Furthermore, in-depth interview data were also collected from 24 students who volunteered further insights. Results revealed that SLI had a strong positive effect on SSK ($\beta = 0.62$, $p < .001$) and SSA ($\beta = 0.57$, $p < .001$), with SE acting as a significant mediator. The qualitative data showed community-related programs and structured reflection were key elements in changing students' worldviews concerning sustainability issues. The findings also showed, through H6, that SLI increases SE and that increased SE improves SSK and SSA. These results make a strong case for systematically integrating sustainability into academic curricula, supported by experiential learning activities, to develop competencies in sustainability. If the goal is to be achieved, universities must invest in faculty capacity-building and real-world experiential learning to prepare responsible global citizens.

1. INTRODUCTION

The world is currently experiencing a 'polycrisis' comprising climate change, heightened social disparities, and fragile economic systems, which call for urgent systemic responses [1]. Once an idealistic goal, sustainable development has now become an imperative for survival, with many higher educational institutions positioned to lead the transformation.

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has frequently advocated that higher education institutions shift toward becoming incubators of sustainability literacy [2], which requires blending knowledge, skills, and attitudes for addressing complex global issues [3].

In an effort to embrace these sustainability goals, Thailand has implemented its national Bio-Circular-Green (BCG) Economy model [4], which prioritizes sustainable growth. Thai universities have also begun incorporating the Sustainable Development Goals (SDGs) into their strategic plans [5], but unfortunately, gaps remain between policy and practice. One such gap is the reliance of instructors and their courses on traditional lectures, with students rarely engaging in hands-on, community-based learning that would connect sustainability concepts to real-world problems [6, 7]. Studies have shown that integrated learning for global citizenship can build knowledge, values, and attitudes. However, few Thai studies have tested a formal model linking curriculum design, student engagement, and sustainability outcomes using robust quantitative methods.

Despite growing interest in Education for Sustainable Development (ESD) in Thailand [8, 9], several gaps remain unaddressed. First, no empirical study has tested a structural model linking Sustainability Learning Integration (SLI) – defined as the deliberate combination of sustainability content, experiential activities, and structured reflection – to graduate students' sustainability knowledge (SSK) and attitudes (SSA) with student engagement as a potential mediator [10-12]. Second, existing Thai studies on sustainability education have predominantly employed qualitative methods or simple pre-post design without a control group, limiting their ability to establish causal pathways or generalize findings. Third, while international research has demonstrated positive effects of engagement on learning outcomes, no study has validated these relationships within the Thai higher education context using structural equation modeling (SEM). Consequently, university administrators and curriculum planners lack evidence-based guidance on whether to invest limited resources in curriculum redesign, faculty training, or

experiential learning infrastructure. The present study addresses these gaps by: (a) proposing and testing a theoretically grounded SEM model (H1–H6), (b) using a large sample (n = 520) from six Thai universities, and (c) employing a mixed-methods sequential explanatory design to both quantify effects and explain underlying mechanisms.

2. LITERATURE REVIEW

2.1 Education for sustainable development in higher education

UNESCO [13] has designed a framework for ESD that requires integrating sustainability at all levels of education [14]. In higher education, this means developing new curricula, implementing pedagogical innovations, and fostering institutional culture change. Lozano et al. [15] conducted a literature review of 84 studies concerning sustainability competencies. Based on their research, the authors concluded that project-based, problem-based, and interdisciplinary approaches are most effective for fostering the critical competencies for sustainable development. These include systems thinking, critical thinking, collaboration, and normative competencies. This is consistent with the study of Shephard et al. [16], further showing that values-based learning, such as ethical dimensions, has a lasting impact on students' attitudes, more so than factual instruction alone.

In studies across Asia and the Middle East, multiple scholars have explored ESD. Oe et al. [17] in Japan found that community-based projects and reflective journals significantly increased students' awareness of sustainability issues. According to Amin et al. [18], barriers to ESD implementation in the Gulf Corporation Council (GCC) are nearly identical to those in Europe, indicating that the problem lies not in regional peculiarities but in a systemic, epistemological crisis within contemporary education that fundamentally works against the holistic, interdisciplinary, and values-driven nature of ESD. However, these studies were mostly qualitative or used simple pre-post designs. A comprehensive SEM model linking SLI, engagement, knowledge, and attitudes has been missing – a gap this study directly addresses.

2.2 Experiential learning and sustainability learning integration

The theoretical foundation of the present study rests on two complementary learning theories. First is Kolb's Experiential Learning Theory (ELT), which describes learning as a four-stage cycle. These cycles are concrete experience, reflective observation, abstract conceptualization, and active experimentation [19, 20]. For sustainability education, this means that students need direct encounters with environmental or social issues (e.g., working with a community facing water scarcity) [21], followed by structured reflection to derive general principles (keeping a journal), and finally opportunities to apply those principles in new contexts. Morris also confirmed that experiential learning significantly deepens understanding and changes attitudes, especially when combined with systematic reflection [20].

Second is Mezirow's Transformative Learning Theory (TLT), which explains how adults can shift their fundamental worldviews [22]. Hoggan [23] expanded this framework to include six dimensions of transformation. These included knowledge, identity, worldview, relationships, attitudes, and behavior. Sustainability learning often requires such transformation – moving from a purely economic mindset to one that values ecological and social wellbeing. Therefore, effective SLI must not only inform but also challenge students' assumptions. Based on this theoretical foundation, the following hypotheses were proposed:

H1: *SLI has a positive direct effect on SSK.*
H2: *SLI has a positive direct effect on SSA.*
H3: *SLI has a positive direct effect on SE.*

2.3 Student engagement

Various studies have reported that student engagement is the most important predictor of learning outcomes [12]. Fredricks [24] proposed three dimensions for learning outcomes. These included behavioural (participation, effort), emotional (interest, belonging), and cognitive (self-regulation and strategic thinking). Thus, a high level of engagement in any particular domain would imply that students are not merely present in the classroom, but are actively grappling with complex issues and investing themselves fully, critically thinking through solutions.

It has also been observed that engagement mediates the impact of innovative teaching practices on learning outcomes [25, 26]. Pimdee et al. [27] have shown that blended problem-based learning improved student problem-solving skills, with engagement acting as a mediating factor. Similarly, in sustainability education, one would hypothesize that SLI increases the kind of engagement that increases knowledge and positive attitudes. Therefore, the authors hypothesized:

H4: *SE has a positive direct effect on SSK.*
H5: *SE has a positive direct effect on SSA.*
H6a: *SE mediates the effect of SLI on SSK.*
H6b: *SE mediates the effect of SLI on SSA.*

2.4 Research objectives

Additionally, the authors suggest these research objectives (ROs):

RO1: To examine the direct effects of SLI on SSK, SSA, and SE.

RO2: To examine the direct effects of SE on SSK and SSA.

RO3: To test whether SE mediates the relationship between SLI and the two outcome variables (SSK, SSA).

These objectives directly address the research gaps identified in the Introduction.

2.5 Research questions

The authors suggest these research objectives (RQs):

RQ1: Does SLI have a significant positive direct effect on SSK, SSA, and SE?

RQ2: Does SE have a significant positive direct effect on SSK and SSA?

RQ3: Does SE mediate the effects of SLI on SSK and SSA?

By using a mixed-methods design with a large sample (n = 520) and SEM, this study provides evidence-based insights for curriculum planners and policymakers.

Section 3 describes the mixed-methods methodology. Section 4 presents the quantitative and qualitative results. Section 5 discusses the findings in the context of sustainable development planning, and Section 6 concludes with implications and limitations.

2.6 Conceptual model

Based on the above, the authors propose Figure 1's model, which shows the relationships among SLI (independent variable), SE (mediating variable), SSK (dependent variable), and SSA (dependent variable). H1–H5 represent direct effect hypotheses, while H6a and H6b represent the mediation hypotheses via SE.

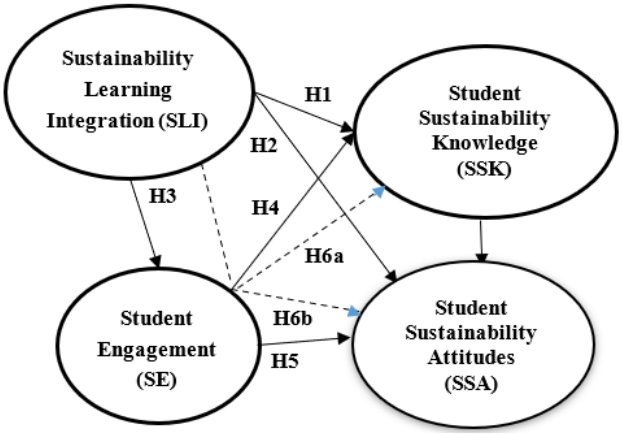

Figure 1. Conceptual model

3. METHODS

3.1 Research design

A mixed-methods sequential explanatory design was employed [28]. First, quantitative data were collected from a large sample of graduate students to test the SEM. Second, qualitative interviews were conducted with a subset of participants to explain and elaborate on the quantitative results [29].

3.1.1 Connection between quantitative and qualitative phases

Following the sequential explanatory design [28, 29], the quantitative phase was conducted first. Data from 520 graduate students were analyzed using SEM to test the hypothesized relationships (H1--H6). The results of the quantitative phase directly informed the qualitative phase in three specific ways.

First, the SEM results revealed that SE significantly mediated the relationships between SLI and both outcome variables (SSK and SSA). Therefore, interview questions were designed to probe *how* and *why* engagement functions as a mediator. Participants were asked to describe specific learning activities that increased their behavioral, emotional, or cognitive engagement (see Appendix A, Questions #1, #3, #6).

Second, the quantitative data showed variation in engagement levels across participants. Using a purposive sampling strategy, 24 students were selected from three engagement categories: high engagement (n = 8, top 20% of SE scores), medium engagement (n = 8, middle 40-60%), and low engagement (n = 8, bottom 20%). This stratification allowed the research team to compare how SLI experiences differed across engagement levels.

Third, the standardized path coefficients indicated that the SLI→SSK pathway (β = 0.62) was slightly stronger than the SLI→SSA pathway (β = 0.57). The qualitative interviews therefore included questions exploring why knowledge acquisition might be more directly influenced by SLI than attitude change. Interviewers used Question #4 from Appendix A ("Did you notice any changes in your attitudes or perspectives toward sustainability issues? How?"), followed by the specific probe: *"Did your beliefs about sustainability change as much as your understanding? Why or why not?"*

All qualitative interview questions (see Appendix A for the full 12-question protocol) were derived directly from these quantitative findings. Follow-up probes were used flexibly to elicit deeper responses. This ensured that the qualitative phase served to explain, elaborate on, and contextualize the statistical results rather than simply collecting parallel data.

3.2 Participants and sampling

The target population comprised graduate students (master's and doctoral) enrolled in six public universities in Thailand who had participated in sustainability-related courses or activities [30]. A multistage sampling procedure was employed to ensure representativeness and replicability, consisting of four sequential stages.

Stage 1 (Region selection). Four geographic regions of Thailand were purposively selected to capture regional diversity: Bangkok Metropolitan Region (central), Northern Region, Northeastern Region, and Southern Region. These regions represent distinct socioeconomic and environmental contexts relevant to sustainability education.

Stage 2 (University selection). From each of the four regions, six public universities were randomly selected from the Office of the Higher Education Commission's list of accredited institutions. A total of six universities participated (two from Bangkok, and one from each of the other three regions). University names are withheld to protect participant confidentiality.

Stage 3 (Course identification). Within each university, all graduate-level courses offered during the second semester of the 2024 academic year were reviewed by the research team. Courses were eligible for inclusion if the syllabus explicitly contained at least three of the following SLI elements: (a) SDG-related content covered across multiple weeks, (b) project-based learning addressing real-world sustainability problems, (c) community engagement activities, (d) structured reflective assignments (e.g., journals, portfolios), and (e) interdisciplinary sustainability projects. A total of 42 courses met these criteria across the six universities.

Stage 4 (Student sampling). From each eligible course, students were randomly sampled using a simple random sampling method (lottery technique). A total of 520 students agreed to participate and completed the survey, representing a response rate of 78.2% (520 of 665 invited). The sample included students from four faculties: Education (n = 136, 26.15%), Business Administration/Economics (n = 133, 25.58%), Science and Technology (n = 128, 24.62%), and Social Sciences/Humanities (n = 123, 23.65%).

Qualitative subsample. For the qualitative phase, 24 students were purposively selected from the quantitative sample using stratified purposive sampling. Participants were selected based on their student engagement (SE) scores, with eight students drawn from each of three categories: high engagement (top 20% of SE scores, >4.2 on a 5-point scale), medium engagement (middle 40-60%, SE scores between 3.5 and 4.0), and low engagement (bottom 20%, SE scores <2.9). This stratification was designed to capture a range of experiences and to understand how engagement levels shape

the SLI→SSK and SLI→SSA pathways. All 24 invited students agreed to participate in interviews.

3.3 Instruments

All quantitative measures were first developed in Thai. Subsequently, they were translated into English and then back-translated into Thai to ensure semantic equivalence. Five experts assessed content validity, and each item scored above 0.80 on the Index of Item-Objective Congruence (IOC) [31]. Cronbach's alpha exceeded 0.85 for each scale, indicating acceptable internal consistency.

3.3.1 Sustainability learning integration scale

The SLI scale was developed de novo for the present study. No existing scale was directly adapted. Item generation was guided by two theoretical frameworks: Kolb's ELT [19, 20] and Mezirow's TLT [22, 23]. The operational definition of SLI was constructed as the deliberate combination of three components: (a) sustainability content integration (explicit coverage of SDGs and sustainability concepts), (b) experiential learning processes (project-based, community-engaged, or problem-based activities), and (c) structured reflection opportunities (journals, discussions, or portfolios).

An initial pool of 24 items was generated based on this definition. Items were reviewed by five experts in sustainability education and educational measurement for content validity. After eliminating redundant or ambiguous items, 12 items remained, each with an IOC score above 0.80. The final 12-item scale covered three sub-dimensions (four items each): content integration (e.g., "SDGs were explicitly discussed in the course"), learning process (e.g., "We worked on real-world sustainability problems"), and experiential activities (e.g., "I participated in a community project related to sustainability") [32]. Students answered on a five-point Likert scale from "strongly disagree" (1) to "strongly agree" (5).

All items were measured on a five-point Likert scale ranging from 'strongly disagree' (1) to 'strongly agree' (5).

3.3.2 Student engagement scale

The authors took 15 items from Fredricks [24] and adapted them for our context. The items measured behavioural engagement ("I actively participated in class discussions"), emotional engagement ("I felt excited about sustainability topics"), and cognitive engagement ("I tried to relate what I learned to my own life"). Again, a five-point Likert scale was used.

3.3.3 Sustainability knowledge test

The research team put together 25 multiple-choice questions. They covered SDGs, systems thinking, climate change, social equity, and the circular economy. Reliability was acceptable – the Kuder-Richardson 20 coefficient was 0.82.

3.3.4 Sustainability attitudes scale

Ten items measured values and beliefs. Example statements: "I believe that protecting the environment is more important than economic growth" and "I am willing to change my lifestyle to reduce my carbon footprint" [33].

3.3.5 Interview protocol

For the qualitative part, we used semi-structured questions. The goal was to explore how SLI influenced students' understanding, feelings, and actions regarding sustainability. A typical question was: "Can you describe a specific learning activity that changed the way you think about sustainability?"

3.4 Data collection

Quantitative data were collected during the second semester of the 2024 academic year. With permission from university ethics committees, surveys were administered online (via Google Forms) and in paper format, taking approximately 30 minutes. Participation was voluntary and anonymous. Qualitative interviews (45-60 minutes each) were conducted via video call, audio-recorded, and transcribed verbatim.

3.5 Data analysis

Quantitative data were analysed using SPSS for descriptive statistics, and LISREL 9.10 was used for SEM. The model fit was assessed using χ^2/df, CFI, GFI, SRMR, and RMSEA [34]. Mediation effects were examined using bootstrapping (5,000 resamples). Qualitative data were analysed using thematic analysis, with codes and themes identified inductively from the transcripts.

4. RESULTS

4.1 Student characteristics (n = 520)

We had 520 respondents in total, with the majority being female (55.77%) (Table 1). Concerning age, the largest group was 26–30 years old (31.73%), followed by 31–35 years old (27.69%), and finally, the younger 22–25 age group with only 15.58%.

As for Education, master's students made up the majority (68.85%), while doctoral students accounted for 31.15%. The four faculties were fairly evenly distributed across Education at 26.15%, Business/Economics at 25.58%, Science and Technology at 24.62%, and finally, the Social Sciences/Humanities at 23.65%.

Table 1. Student characteristics (n = 520)

Variable	Category / Level	n	%
Gender	Male	230	44.23
	Female	290	55.77
Age	22–25 years of age	81	15.58
	26–30 years of age	165	31.73
	31–35 years of age	144	27.69
	36–40 years of age	82	15.77
	41 and up	48	9.23
Education level	Master's degree	358	68.85
	Doctoral degree	162	31.15
Faculty / Discipline	Education	136	26.15
	Social Sciences / Humanities	123	23.65
	Business Administration / Economics	133	25.58
	Science and Technology	128	24.62
Work status	Full-time student	201	38.65
	Working while studying	319	61.35
Total		**520**	**100.00**

Regarding work status, most respondents (61.35%) worked while studying, and the remaining 38.65% were full-time students. So the sample was largely composed of graduate

students balancing jobs with their studies.

It has been suggested that the seemingly older Thai graduate students in the sample are in graduate classes for multiple reasons. First, over 60% of them were working while studying, which is very common in Thailand, where many grad students enrol part-time while holding down a job. Second, nearly a third were PhD students, who are typically older than master's students. In the Thai system, people often work for a few years before starting graduate school, so the 26–35 age range is pretty typical for master's and early-stage doctoral students. The small number of students over 41 (just 9%) is probably either late-stage PhD candidates or mid-career professionals going back for another degree – not unusual in education or social science fields.

4.2 Descriptive statistics

Table 2 presents the means (*M*) and standard deviations (*SD*) for the main variables. All mean scores were above the mid-point (3.0), indicating generally positive perceptions. SSA toward sustainability were highest (*M* = 4.02), followed by SSK (*M* = 3.87) and SE (*M* = 3.75).

Table 2. Descriptive statistics of latent variables

Variable	*M*	*SD*
Sustainability Learning Integration (SLI)	3.91	0.67
Student Engagement	3.75	0.65
Student Sustainability Knowledge (SSK)	3.87	0.62
Student Sustainability Attitudes (SSA)	4.02	0.58

Note: All variables measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), except SSK which was a 25-item knowledge test (score range 0–5 converted to 5-point scale for comparability).

4.3 Measurement model validation (Confirmatory Factor Analysis-CFA)

The CFA showed that all indicators loaded significantly on their respective constructs (loadings > 0.70). Composite reliability (CR) ranged from 0.88 to 0.93, and average variance extracted (AVE) from 0.65 to 0.72, supporting convergent validity. Discriminant validity was confirmed because the square root of AVE for each construct exceeded its correlations with other constructs [35].

Table 3 presents the standardized factor loadings for all items, along with CR and AVE for each construct. All factor loadings exceeded the recommended threshold of 0.70 [35], indicating that each item adequately represented its respective latent construct. CR values ranged from 0.88 to 0.93, exceeding the acceptable criterion of 0.70 and demonstrating high internal consistency. AVE values ranged from 0.65 to 0.72, all above the recommended minimum of 0.50, thereby supporting convergent validity.

4.4 Structural model and hypothesis testing

There was an excellent fit between the data and the SEM as $\chi^2/df = 2.14$, CFI = 0.97, GFI = 0.94, SRMR = 0.05, and RMSEA = 0.06. Figure 2 shows the final model with standardized path coefficients. Table 4 shows the SEM's standardized DEs, while Table 5 identifies the indirect mediated) effect via SE. All hypotheses were supported. The model explained 58% of the variance in SSK and 52% in SSA.

Table 3. Standardized factor loadings, composite reliability (CR), and average variance extracted (AVE)

Construct	Item	SL	CR	AVE
Sustainability Learning Integration (SLI)	SLI1	0.82	0.93	0.69
	SLI2	0.79		
	SLI3	0.81		
	SLI4	0.77		
	SLI5	0.84		
	SLI6	0.86		
	SLI7	0.80		
	SLI8	0.78		
	SLI9	0.83		
	SLI10	0.81		
	SLI11	0.85		
	SLI12	0.79		
Student Engagement	SE1	0.80	0.94	0.67
	SE2	0.82		
	SE3	0.79		
	SE4	0.84		
	SE5	0.81		
	SE6	0.83		
	SE7	0.78		
	SE8	0.85		
	SE9	0.76		
	SE10	0.82		
	SE11	0.84		
	SE12	0.80		
	SE13	0.86		
	SE14	0.77		
	SE15	0.83		
Sustainability Skills Knowledge (SSK)	SSK1	0.78	0.96	0.64
	SSK2	0.81		
	SSK3	0.76		
	SSK4	0.80		
	SSK5	0.82		
	SSK6	0.79		
	SSK7	0.77		
	SSK8	0.84		
	SSK9	0.81		
	SSK10	0.75		
	SSK11	0.83		
	SSK12	0.79		
	SSK13	0.82		
	SSK14	0.78		
	SSK15	0.85		
	SSK16	0.80		
	SSK17	0.76		
	SSK18	0.81		
	SSK19	0.79		
	SSK20	0.84		
	SSK21	0.77		
	SSK22	0.82		
	SSK23	0.80		
	SSK24	0.78		
	SSK25	0.83		
Sustainability Attitudes (SSA)	SSA1	0.81	0.92	0.70
	SSA2	0.84		
	SSA3	0.79		
	SSA4	0.85		
	SSA5	0.82		
	SSA6	0.86		
	SSA7	0.80		
	SSA8	0.83		
	SSA9	0.78		
	SSA10	0.84		

Table 4. Standardized direct effects (DE) from structural equation modeling (SEM)

Path	*β*	*T-Value*	*p*
H1: SLI → SSK	0.62	8.45	< .001
H2: SLI → SSA	0.57	7.92	< .001
H3: SLI → SE	0.68	9.13	< .001
H4: SE → SSK	0.35	4.21	< .001
H5: SE → SSA	0.29	3.58	< .01

Note: Model fit: $\chi^2/df = 2.14$, CFI = 0.97, GFI = 0.94, SRMR = 0.05, RMSEA = 0.06.

Table 5. Indirect (mediation) effects via student engagement

Path	Indirect β	95% CI	p
SLI → SE → SSK (H6a)	0.24	[0.16, 0.33]	< .01
SLI → SE → SSA (H6b)	0.20	[0.12, 0.29]	< .01

Note: Bootstrapping with 5,000 resamples. CI = confidence interval.

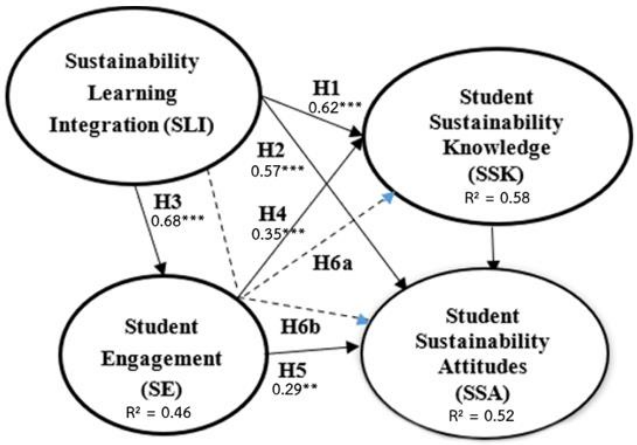

Figure 2. Final structural equation modeling (SEM) with standardized path coefficients

Note: 1. Final SEM with standardized path coefficients. ***p < .001. 2. R^2 values represent the proportion of variance explained for each endogenous variable. 3. H1: SLI → SSK: β = 0.62***, H2: SLI → SSA: β = 0.57***, H3: SLI → SE: β = 0.68***, H4: SE → SSK: β = 0.35***. H5: SE → SSA: β = 0.29**, SE R^2 = 0.46, SSK = R^2 = 0.58, SSA R^2 = 0.52.

4.5 Qualitative findings

Semi-structured interviews were conducted with 24 graduate students purposively selected from the quantitative sample based on their engagement scores (high, n = 8; medium, n = 8; low, n = 8). Interviews lasted 45–60 minutes and were transcribed verbatim. Thematic analysis was guided by the 12 interview questions (see Appendix A). Table 6 summarizes participant responses by question. Below, key findings are organized by theme.

4.5.1 Synthesis of qualitative findings

Across all three themes, a clear pattern emerged: effective SLI requires not only exposure to sustainability content but also (a) direct experiential encounters with real-world problems, (b) structured opportunities for reflection to consolidate learning, and (c) emotional engagement to facilitate attitude change. Students who experienced all three elements (high engagement group) consistently reported deeper knowledge and transformed attitudes. Those who experienced only one or two elements (medium and low engagement groups) reported weaker outcomes. These qualitative findings align with and elaborate upon the quantitative SEM results, particularly the mediation role of student engagement (H6a, H6b).

Table 6. Summary of interview findings by question

Question Topic	Key Findings from Participants
1. Learning activity that changed thinking about sustainability	Project-based learning, case study analysis, and community field visits were most frequently mentioned. These activities helped students see sustainability as a real-life issue rather than an abstract concept.
2. Influence on understanding	Students reported improved systems thinking, clearer understanding of linkages between environment, society, and economy, and better comprehension of the SDGs.
3. Effects on feelings and actions	Students felt increased awareness and social responsibility. Behavioural changes included reduced plastic use, waste separation, and daily lifestyle adjustments.
4. Changes in attitudes or perspectives	Most students developed more positive attitudes toward sustainable development, viewing it as related to quality of life and social equity, not only the environment.
5. Experiences that created most awareness	Community field visits, direct engagement with communities, and witnessing real environmental impacts (e.g., waste, water pollution) were most impactful.
6. Effect of participation in projects/activities	Hands-on participation deepened learning, improved collaboration skills, analytical thinking, and problem-solving in real-world contexts.
7. Factors that supported learning	Participatory teaching methods, instructors who encouraged discussion, learning materials linked to real situations, and experiential activities.
8. Barriers to learning	Some content was complex and time-consuming; lack of continuous opportunities for field activities or hands-on projects.
9. Role of instructors	Instructors play a key role in stimulating critical thinking, connecting content to real life, and facilitating learning.
10. Application of knowledge to real life	Students applied knowledge to work, daily life, and decision-making (e.g., energy conservation, waste management, social activity planning).
11. Suggestions for improvement	Increase field activities, community projects, real case studies, and integrate sustainability across all courses.
12. Additional reflections	Sustainability learning developed knowledge, skills, and consciousness while inspiring personal and social change.

4.5.2 Summary of qualitative findings

The interview findings supported and elaborated upon the quantitative SEM results. First, experiential learning activities (community projects, field visits, case studies) were identified as the most powerful triggers for transformative change, consistent with the strong SLI→SE path (β = 0.68). Second, students who reported higher engagement also reported deeper knowledge retention and attitude change, aligning with the mediation findings (H6a, H6b). Third, barriers such as limited field opportunities and complex content suggest areas for

curriculum improvement. Overall, the qualitative data confirmed that effective SLI requires authentic experiential activities, structured reflection, and emotional engagement to produce lasting knowledge and attitude change.

5. DISCUSSION

This study examined how integrating sustainability learning into graduate courses affects SSK, SSA, and SE, with student engagement as a potential mediator. The results strongly support the proposed model and offer several theoretical and practical insights for sustainable development planning in higher education.

5.1 Direct effects of Sustainability Learning Integration on knowledge, attitudes, and engagement

The finding that SLI had a strong positive effect on SSK ($\beta = 0.62$, $p < .001$) and SSA ($\beta = 0.57$, $p < .001$) confirms and extends prior international research [15-16, 36] while providing the first empirical validation of such relationships in the Thai higher education context [37]. The magnitude of these effects is noteworthy: SLI explained 58% of the variance in knowledge and 52% of the variance in attitudes. The course design requires students to study sustainability materials throughout the term while engaging in experiential learning opportunities in real-world community contexts [38]. In practical terms, this means that students who experienced well-designed SLI – combining content, experiential activities, and reflection – scored substantially higher on both outcome measures than those who did not [39].

From a theoretical perspective, these results align with Kolb's Experiential Learning Theory [19, 20]. Kolb argued that learning is most effective when learners cycle through concrete experience, reflective observation, abstract conceptualization, and active experimentation. The SLI scale in this study explicitly measured all four components. Therefore, the strong SLI→SSK pathway suggests that sustainability knowledge is not simply transmitted from instructor to student but is actively constructed through direct engagement with real-world problems. These findings challenge traditional lecture-dominated approaches still common in many Thai universities [6, 7].

The slightly weaker effect of SLI on attitudes ($\beta = 0.57$ versus 0.62 for knowledge) is also theoretically meaningful. Mezirow's Transformative Learning Theory [22, 23] posits that attitude and value change are more difficult to achieve than knowledge acquisition because they require learners to critically examine and potentially abandon deeply held assumptions. In the Thai cultural context [37], where hierarchical relationships and saving face are highly valued, challenging one's own worldview may be particularly uncomfortable. The qualitative findings support this interpretation: students who reported attitude change almost always described an emotionally charged experience (e.g., "I almost cried," "I broke down") rather than a purely intellectual one.

The strong direct effect of SLI on SE ($\beta = 0.68$, $p < .001$) indicates that how sustainability is taught matters as much as what is taught. Students became more engaged – behaviourally, emotionally, and cognitively – when courses incorporated experiential learning and structured reflection. This finding has practical implications for faculty development: training instructors to design and facilitate experiential learning activities may yield higher returns on investment than simply adding sustainability content to existing lectures.

5.2 The mediating role of student engagement

The significant mediation effects (SLI → SE → SSK: indirect $\beta = 0.24$, $p < .01$; SLI → SE → SSA: indirect $\beta = 0.20$, $p < .01$) demonstrate that engagement is not merely a desirable outcome but a mechanism through which SLI produces learning gains. In other words, SLI works partly because it increases student engagement, and increased engagement then leads to better knowledge and attitudes.

This finding is consistent with Fredricks' three-dimensional model of engagement [24] and with prior research showing engagement as a mediator of innovative teaching practices [25-27]. However, the partial nature of the mediation (direct effects remained significant even after accounting for engagement) suggests that SLI also influences knowledge and attitudes through other pathways not captured in this model. Possible alternative mechanisms include increased self-efficacy, development of sustainability identities, or shifts in moral reasoning. Future research should explore these possibilities.

For sustainable development planning, the mediation finding has a clear implication: universities should monitor student engagement as an early indicator of sustainability learning outcomes. Engagement is easier to measure in real-time (e.g., through classroom observations, learning analytics, or brief surveys) than knowledge or attitude change, which typically require end-of-term assessments. Low engagement scores mid-semester could trigger instructional interventions before it is too late.

5.3 Implications for Thailand's Bio-Circular-Green economy model and sustainable development goals

Thailand's national BCG Economy model [4] prioritizes sustainable growth but has been criticized for remaining at the policy level without sufficient implementation in educational settings [5, 40]. The present study provides empirical evidence that specific, actionable curriculum designs – not just policy statements – can produce measurable sustainability learning outcomes.

Specifically, the finding that community-based projects and structured reflection were most effective (from qualitative data) suggests that Thai universities should allocate resources to: (a) developing partnerships with local communities and NGOs to provide authentic project sites, (b) training faculty in experiential and reflective pedagogies, and (c) revising curriculum approval processes to require explicit SLI elements rather than generic sustainability statements.

These actions align directly with SDG 4 (Quality Education), which calls for ensuring all learners acquire knowledge and skills needed for sustainable development, and SDG 12 (Responsible Consumption and Production), which emphasizes education for sustainable lifestyles [41]. The model's high explained variance ($R^2 = 0.58$ for knowledge, 0.52 for attitudes) indicates that well-designed SLI can achieve substantial progress toward these goals even within a single semester.

5.4 Comparison with prior Thai studies

Previous Thai research on sustainability education has been predominantly qualitative [17, 18] or used simple pre-post designs without control groups. While these studies provided valuable initial insights, they could not establish causal pathways or generalize findings beyond small samples. The present study advances the field by: (a) testing a theory-driven SEM model, (b) using a large sample (n = 520) across multiple universities and disciplines, and (c) employing a mixed-methods design that both quantifies effects and explains underlying mechanisms.

The qualitative findings echo Oe et al. [17], who found that in Japan community-based projects and reflective journals increased sustainability awareness. However, the present study goes further by demonstrating that these effects are partially mediated by engagement and that engagement itself is predicted by SLI. This suggests that prior Thai studies may have underestimated the importance of engagement as an intermediate outcome.

5.5 Limitations acknowledged in interpretation

Several limitations should be considered when interpreting these findings. First, the cross-sectional design prevents strong causal claims. Although the SEM results are consistent with causal pathways hypothesized from theory, longitudinal data would provide stronger evidence. Second, all measures were self-reported except the knowledge test, raising the possibility of common method bias. Third, the sample included only graduate students from six public universities; findings may not generalize to undergraduate or vocational students, or to private universities. Fourth, the qualitative sample (n = 24) was drawn from the same population as the quantitative sample, limiting the diversity of perspectives. Future research should address these limitations through longitudinal designs, multi-informant measures (e.g., peer or instructor ratings of engagement), and more diverse samples.

6. CONCLUSIONS

The research developed and validated a structural model that demonstrated how sustainability learning programs are integrated into Thai graduate education systems. The study identified two primary outcomes: SLI, a learning method that combines content with experiential activities and reflection, enables students to acquire knowledge about sustainable development while developing positive attitudes toward it. The study also showed that all three types of student engagement (behavioral, emotional, and cognitive) function as partial mediators: students who actively participate in learning activities acquire more knowledge while developing deeper environmental protection values. Additionally, the study found that community-based projects, together with structured reflective writing, are the most effective methods for facilitating transformational change, according to qualitative evidence.

6.1 Implications for sustainable development planning

For educational planners and university administrators, the findings suggest concrete actions:

Revise curricula to embed SDGs across disciplines, not just in environmental or social science courses.

Train faculty in experiential and reflective pedagogies; move away from pure lecturing.

Create partnerships with local communities and NGOs to provide authentic project sites for students.

Measure engagement as an early indicator of sustainability learning outcomes.

These steps align with Thailand's BCG model [40] and contribute to SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production) by fostering sustainability-minded graduates [41].

6.2 Limitations and future research

The research findings have limitations that need to be acknowledged. As the research design prevents researchers from establishing cause-and-effect relationships, researchers should conduct longitudinal studies to obtain additional data. The study included only graduate students from six universities because undergraduate students and vocational students have different profiles. Future studies should include control groups (e.g., students in traditional courses without SLI) and measure actual behaviour change (e.g., recycling, energy-saving) rather than only self-reported attitudes. The research provides a robust, validated framework to develop sustainability education programs in Thailand and other countries.

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NOMENCLATURE

CFI	Comparative Fit Index
CR	Composite reliability
df	Degrees of freedom
GFI	Goodness-of-Fit Index
M	Arithmetic mean
p	Probability value (significance)
R^2	Coefficient of determination
RMSEA	Root Mean Square Error of Approximation
SD	Standard deviation
SEM	Structural equation model
SLI	Sustainability learning integration
SRMR	Standardized Root Mean Square Residual
t	Student's t-statistic

Symbols

α	Cronbach's alpha (internal consistency coefficient)
β	Standardized path coefficient (regression weight)
χ^2	Chi-square statistic

Notes: 1. All symbols are dimensionless statistical measures; no SI units apply. 2. β refers to the direct effect between latent variables in the structural model. 3. R^2 represents the proportion of variance explained for endogenous variables.

APPENDIX

APPENDIX A: Semi-Structured Interview Questions

The following 12 questions guided the qualitative interviews. Questions were derived directly from the quantitative SEM results to probe mediation pathways, engagement levels, and differential effects on knowledge versus attitudes.

1. Please describe a specific learning activity that changed the way you think about sustainability.
2. How did learning about sustainability influence your understanding?
3. How did this learning affect your feelings and actions regarding sustainability?
4. Did you notice any changes in your attitudes or perspectives toward sustainability issues? How?
5. What experiences made you most aware of environmental or social problems?
6. How did participation in activities (e.g., projects, field visits) affect your learning?
7. What factors supported your sustainability learning (e.g., instructors, teaching methods, learning materials)?
8. What factors or barriers affected your learning in this area?
9. What is your opinion on the role of instructors in promoting sustainability learning?
10. How have you applied the knowledge or experiences you gained to real life or other contexts?
11. What suggestions do you have for improving sustainability learning management in the future?
12. Is there anything else you would like to add about your sustainability learning experience?

Table A. Semi-structured interview questions

#	**Interview Question (translated)**
1	Please describe a specific learning activity that changed the way you think about sustainability.
2	How did learning about sustainability influence your understanding?
3	How did this learning affect your feelings and actions regarding sustainability?
4	Did you notice any changes in your attitudes or perspectives toward sustainability issues? How?
5	What experiences made you most aware of environmental or social problems?
6	How did participation in activities (e.g., projects, field visits) affect your learning?
7	What factors supported your sustainability learning (e.g., instructors, teaching methods, learning materials)?
8	What factors or barriers affected your learning in this area?
9	What is your opinion on the role of instructors in promoting sustainability learning?
10	How have you applied the knowledge or experiences you gained to real life or other contexts?
11	What suggestions do you have for improving sustainability learning management in the future?
12	Is there anything else you would like to add about your sustainability learning experience?

Note: The original Thai-language protocol is available from the corresponding author upon request.