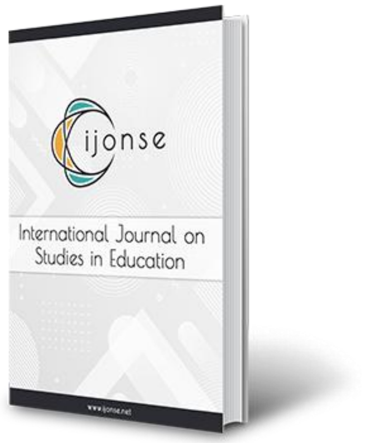

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Bridging the Gap among Knowledge, Attitudes, and Behaviors toward Sustainable Development through I-STEM-PBL-ESD

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Abstract

Bridging the gap among knowledge, attitudes, and behaviors (KAB) is essential for achieving sustainable development (SD). This study examined changes in students' KAB, before and after the implementation of Integrated Science, Technology, Engineering, and Mathematics - Problem-Based Learning - Education for Sustainable Development (I-STEM-PBL-ESD) modules. Employing a quantitative descriptive survey research design, the study targeted Filipino Grade 11 STEM students (n = 38) enrolled in General Biology 1. Data were collected using the OSISDeP (pretest and posttest) tool to measure KAB, and the I-STEM-PBL-ESD modules as learning interventions. The results revealed significant improvements in students' KAB, demonstrating enhanced understanding of SD, more positive attitudes toward its socio-economic and environmental aspects, and increased engagement in behaviors supportive of sustainability. Notably, the study observed a close alignment between knowledge and attitudes after the intervention, while the relationship between knowledge and behaviors remained relatively stable. These findings highlight the effectiveness of active learning methods, such as I-STEM-PBL-ESD, in shaping students' perspectives and emphasize the need for further progress through practical community engagement to bridge the gap between knowledge and behaviors, ultimately promoting sustainable practices.

Introduction

The Knowledge, Attitudes, and Behaviors (KAB) model serves as a foundational framework in education for comprehending the intricate interplay between learning, attitudes, and behavioral change. This model underscores the significance of addressing attitudes alongside knowledge to foster transformative behaviors (Fishbein & Ajzen, 2010). Concurrently, it acknowledges the influence of education and experiences on attitudes and values, thereby shaping behavioral patterns (Bandura, 1977). However, while the KAB model offers a comprehensive perspective on these dynamics, it does not explicitly explore the application of this model within the context of Integrated Science, Technology, Engineering, and Mathematics - Problem-Based Learning - Education for Sustainable Development (I-STEM-PBL-ESD) initiatives (Funa et al., in press). Consequently, a gap emerges in understanding how this multifaceted educational approach may leverage the KAB model to advance science competence, particularly in relation to sustainable development (SD). This study seeks to bridge this gap by investigating the synergistic potential of I-STEM-PBL-ESD in enhancing students' science competence through targeted interventions that address the KAB domains.

The literature surrounding the three domains of the KAB model underscores their interconnectedness and importance in educational and behavioral research. Knowledge, as a fundamental domain, has been extensively studied in the context of various educational approaches (Bandura, 1977). Knowledge refers to information, understanding, facts, and skills acquired through learning, experience, education, observation, or interaction with the environment. It involves the awareness and comprehension of concepts, principles, and information relevant to various subjects or areas of study. Research has shown that individuals acquire knowledge through diverse means, such as formal education, personal experiences, and socialization (Bronfenbrenner, 1977). This domain is essential for understanding the cognitive foundations of attitudes and behaviors. Attitudes, the second domain, have garnered substantial attention due to their role in shaping behavior (Fishbein & Ajzen, 2010). Attitudes encompass individuals' evaluations, feelings, beliefs, and predispositions towards people, objects, ideas, or situations. These attitudes can be positive, negative, or neutral and are shaped by a combination of personal experiences, social influences, cultural factors, and knowledge. Studies have demonstrated that attitudes are influenced by personal experiences, socialization, and education (Bandura, 1977; Fishbein & Ajzen, 2010). Attitudes are malleable and can be influenced by interventions that address both individual and environmental factors. Lastly, the domain of Behaviors has been explored extensively in the fields of psychology and education (Bronfenbrenner, 1977). Behaviors represent observable actions, responses, or conduct demonstrated by individuals in various situations. They encompass a wide range of actions, from simple actions to complex behavioral patterns, influenced by attitudes, beliefs, social norms, values, and environmental factors. Behaviors are influenced by a combination of factors, including attitudes, values, and knowledge. Social norms and physical surroundings also play a pivotal role in shaping behaviors, highlighting the significance of both individual and environmental determinants (Bronfenbrenner, 1977). Literature has emphasized the complex interplay between these domains and their impact on learning outcomes and behavioral change. Hence, it is important to examine the interrelatedness of these domains within the context of the I-STEM-PBL-ESD framework, contributing to a more holistic understanding of how knowledge, attitudes, and behaviors collectively shape science competence and SD awareness.

Over the years, STEM has garnered significant attention for its potential to elevate the quality of science and mathematics education globally (Honey et al., 2014). STEM education has been hailed as a solution for nurturing individuals capable of comprehending the intricacies of the world and fostering future innovators to bolster economies and SD efforts (Marrero et al., 2014; Tan et al., 2019). Despite its recognition, a unified understanding of STEM education remains elusive among educators, resulting in varying perspectives on integration and quality education (Honey et al., 2014; Kelley & Knowles, 2016). The formation of STEM initially aimed to unite Science, Technology, Engineering, and Mathematics, acting as a platform to enhance economic growth, innovation, and national security (Bybee, 2013). This education approach emphasizes a multifaceted learning experience that enhances students' comprehension of processes, fosters problem-solving skills, and develops 21st-century competencies (Bybee, 2010). While STEM education continues to advance global capabilities, educators and students alike often struggle to capitalize on its potential, given its complex role, implementation, and evaluation

(Koh, 2018). Amid these complexities, the I-STEM approach emerges as a solution, focusing on the interplay among disciplines to address multifaceted challenges and empower students with holistic problem-solving skills. This study recognizes the evolving definitions and frameworks surrounding I-STEM, aiming to harness its potential to equip students with comprehensive problem-solving strategies that combine disciplinary knowledge with real-world application, particularly in the context of SD.

The integration of PBL and I-STEM has garnered substantial interest for its potential to cultivate higher-order thinking skills and address real-world challenges in education. PBL has demonstrated a positive influence on students' interests in future STEM careers, while the combination of PBL with STEM education has been recognized as an effective approach to foster cognitive, content, and collaborative learning skills (LaForce et al., 2017; El Sayary et al., 2015). This synergistic approach encourages critical thinking, creativity, interdisciplinary connections, and collaborative skills, leading to a holistic educational experience. PBL is particularly adept at equipping students with problem-solving abilities tailored to ill-structured real-world problems, enhancing their competencies as challenges become more complex (Capraro et al., 2013; Russell et al., 2007; Lopatto, 2004). The categorization of PBL into distinct levels based on problem structuredness and self-directedness underscores its adaptability for various educational contexts (Barrows, 1986).

Moreover, the concept of utilizing a collection of problems as a curricular foundation highlights PBL's potential to stimulate engagement and learning across relevant disciplines (Barrows, 1996). Given these insights, the integration of pure PBL, with its emphasis on authentic real-world problems, and an integrated STEM approach emerges as a promising educational strategy. As such, the potential synergies between PBL and I-STEM have piqued interest due to their shared goals of enhancing conceptual understanding, fostering creativity, and cultivating problem-solving abilities (Funa et al., in press). The combination of these approaches holds the promise of offering a potent pedagogical framework that can enrich science education and empower learners to tackle complex challenges effectively.

Despite the recognized potential of I-STEM-PBL to enhance science competence and address real-world challenges toward SD, a critical gap remains in understanding the effective integration of these domains within the educational context (Funa et al., in press). While the KAB model underscores the importance of addressing knowledge, attitudes, and behaviors collectively, limited research has investigated how the I-STEM-PBL can holistically leverage these domains to promote science competence and SD awareness. Thus, this study seeks to address the following research questions: (1) What are the effects of I-STEM-PBL on students' knowledge, attitudes, and behaviors toward SD? and (2) How are the KAB domains interconnected before and after implementing the I-STEM-PBL-ESD framework?

Method

Research Design

The study employed a quantitative descriptive survey research design to investigate the effects of the I-STEM-PBL-ESD framework on students' KAB toward SD (Creswell & Creswell, 2023). The research was conducted in a secondary educational setting, involving a purposive sample of students. A pre-test and post-test design was utilized to gather data before and after the implementation of the I-STEM-PBL-ESD framework. Quantitative data were collected through a Likert-scale survey tailored to measure changes in students' KAB related to SD. Descriptive statistics, including means, standard deviations, and frequencies, were used to analyze the data, providing insights into the extent of changes in knowledge, attitudes, and behaviors. This research design provided a structured and comprehensive approach to investigating the impacts of the I-STEM-PBL-ESD framework within the educational context.

Participants

The study was conducted in a public secondary school in the province of Sorsogon, Bicol (region V), Philippines, chosen due to its significance as a major source of Pili (Canarium ovatum) and the declining local interest in Pili propagation (Sorsogon Pili Board's report, 2018; Sorsogon Pili Roadmap, 2018). Pili (C. ovatum), often referred to as the "Tree of Hope," serves as a compelling context for SD within this study. Indigenous to the Bicol region, Philippines, particularly Albay, Sorsogon, and Samar, Pili (C. ovatum) has garnered significance due to its genetic diversity and its role as a major producer of Pili products nationwide (Millena & Sagum, 2018). Pili (C. ovatum) offers potential for a range of products such as fresh Pili, dried shelled Pili, Pili kernel, Pili pulp oil, and Pili elemi (Catelo & Jimenez, 2016). Notably, Pili pulp oil and Pili nuts hold promise as substitutes for international market favorites like Olive oil and various nuts, contributing to the Philippines' competitive stance globally (Catelo & Jimenez, 2016). The Bicol region has observed substantial growth in Pili (C. ovatum) exports, marked by an annual increase of 40.45% in volume and 46.86% in value from 2008 to 2013 (Catelo & Jimenez, 2016). Despite this potential, there has been a decline in local interest and engagement in traditional Pili (C. ovatum) farming, posing a threat to the industry's sustainability and the continuation of a significant livelihood for the Bicolanos (Sorsogon Pili Roadmap, 2018). This decline, coupled with a lack of interest among Bicolano youth, has led to diminished labor resources for the Pili (C. ovatum) industry and a scarcity of local researchers and scientists dedicated to Pili research and development projects. Given this context, the study recognizes the importance of enhancing understanding, conservation, and active student involvement in the SD of Pili (C. ovatum), making it a pertinent and engaging context for addressing SD challenges, particularly within the Philippines.

The total enumeration sampling method was employed for the student participants (n = 38), who were enrolled in grade 11-STEM, taking General Biology 1, and residing in Bicol, Philippines. On one hand, grade 11-STEM refers to the Philippines' 11th-grade curriculum in a STEM (Science, Technology, Engineering, and Mathematics) track within the educational system. Students who are enrolled in Grade 11-STEM are usually focused on studying subjects related to science, technology, engineering, and mathematics to prepare for further education or careers in these fields. On the other hand, "General Biology 1" is a specific course within the STEM curriculum. It is usually a foundational biology course that covers fundamental topics in biology, such as cell biology and biomolecules, among others (Department of Education [DepEd], 2016). The student participants had previous exposure to PBL through their research courses but were oriented to the specific type of PBL (Pure PBL) used in the study, as well as the I-STEM approach during the orientation phase.

Research Instruments

To comprehensively explore the influence of the I-STEM-PBL-ESD framework on students' KAB toward SD, a set of pre- and post-surveys was designed. These surveys aimed to evaluate shifts in their KAB concerning SD, incorporating Likert-scale items that provide means to gauge participants' perceptions. The KAB assessment instrument, called the Online Survey Instrument for Sustainable Development of Pili (OSISDeP), encompasses a 4-point Likert scale questionnaire with 24 items, equitably distributed among the three KAB domains (Funa, Gabay, Estonanto et al., 2022; Funa, Gabay, Ibardaloza et al., 2022). Tailored to measure students' KAB specifically regarding Pili (C. ovatum) and its SD aspects, the instrument demonstrated strong reliability (α = .835) and suitability for secondary education (κ = 1.00, 95% CI, -1.00 to 1.00) (Funa, Gabay, Estonanto et al., 2022; Funa, Gabay, Ibardaloza et al., 2022).

When implementing instruction through the I-STEM-PBL-ESD framework, the study utilized the I-STEM-PBL Module (Funa, 2023). Before implementation, this module underwent thorough evaluation by six reviewers to ensure alignment with DepEd standards and grade 12 STEM competencies (DepEd, 2021), learner-centeredness - action-orientation - transformative learning (Funa et al., 2023), and STEM integration (Okulu & Oguz-Unver, 2021). The reviewers comprised three master teachers from DepEd and three educators from Higher Education Institutions (HEIs) with diverse expertise in scientific disciplines and English. Results indicated full compliance with DepEd standards, along with minor suggestions for improvement, such as defining terms for clarity in student activities. The development of this instrument was guided by the I-STEM-PBL-ESD instructional framework (Funa et al., in press). Drawing inspiration from the 2nd generation 3C3R problem design model (Hung, 2019), the K-16 PBL model by the Center for PBL (Torp & Sage, 2002), and the I-STEM approach (McComas & Burgin, 2020; Tan et al., 2019) (see Figure 1), the module was thoughtfully designed to foster enriched problems for ESD within the context of Pili (C. ovatum) and its SD.

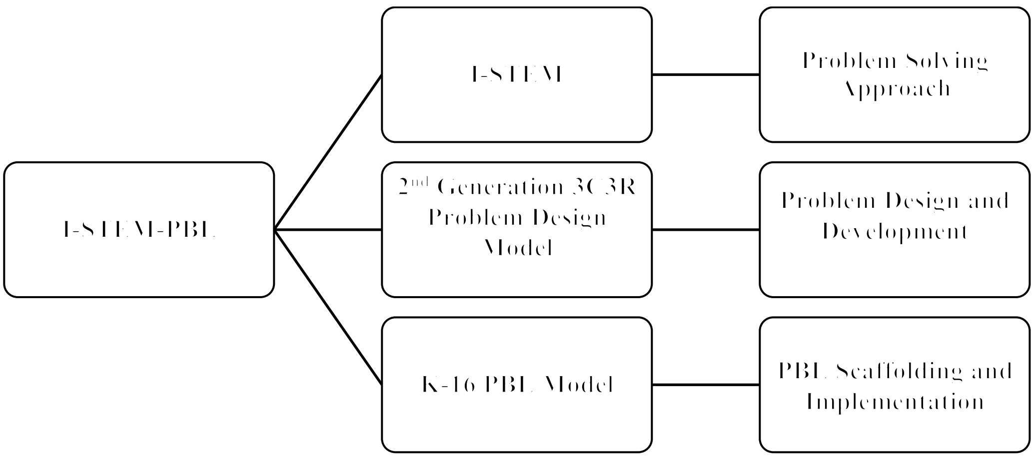

Figure 1. The I-STEM-PBL module and instruction components used in the study.

The module encompasses a series of activities (Funa, 2023), commencing with the first task aimed at preparing learners for subsequent phases. It introduces students to the concept of I-STEM-PBL, elaborates on various PBL types, rationale, and the integration of STEM domains. The module also addresses the roles of students, teachers, and learning environments in PBL. The ensuing phases guide students through the problem-solving journey, encompassing steps such as encountering the problem, identifying existing knowledge and questions, creating concept maps, formulating the problem statement, and generating potential solutions. Furthermore, the module underscores the significance of selecting the most suitable solution, aligned with sustainability criteria. Subsequently, students present their solutions using diverse media, followed by a debriefing activity encouraging reflection on their learning experiences.

Data Gathering Procedures

The data gathering process encompassed three distinct stages: pre-implementation, implementation, and post-implementation. During the pre-implementation phase, the researcher initially collected data by reviewing past studies and conducting a meta-analysis to inform pedagogical approach (Funa, Gabay, Estonanto et al., 2022; Funa, Gabay, Ibardaloza et al., 2022, Funa & Talaue, 2021; Funa & Prudente, 2021). This phase also involved designing, developing, and conducting initial evaluations of the I-STEM-PBL module, with reviewers providing valuable feedback on various aspects, including adherence to DepEd standards (DepEd, 2021), learner-centeredness - action orientation - transformative learning (Funa et al., 2023), and STEM integration (Okulu & Oguz-Unver, 2021). The subsequent implementation stage commenced upon obtaining the necessary permissions, where students were introduced to PBL concepts and assumed responsibility for learning. This phase included pretests and module completion. Finally, the post-implementation stage centered on the analysis of quantitative data, aiming to uncover students' KAB perspectives. The pre-implementation phase spanned from 2021 to 2023 (two years), with module development occurring between January and March 2023 (three months), and the implementation phase taking place from May to July 2023 (three months).

Data Analysis

The data obtained from pretests and posttests using OSISDeP underwent comprehensive analysis. Descriptive statistics, including t-tests, means, standard deviations, frequency, percentage, and ranking, were employed to examine the scores. Furthermore, Pearson’s chi-square was utilized to investigate potential associations among knowledge, attitudes, and behaviors. These OSISDeP scores were grouped into three categories: (a) less than 60%, indicating poor KAB, (b) 60% to 80%, reflecting moderate KAB, and (c) more than 80% to 100%, representing high KAB. By comparing the results of the pretests and posttests, differences and effect sizes were determined.

Results

The researcher evaluated the students' perspectives concerning their KAB aspects SD, considering Pili (C. ovatum). Among these KAB aspects, knowledge pertains to the students' views regarding Pili's SD. Table 1 illustrates how students viewed their knowledge of Pili's SD both before and after the I-STEM-PBL implementation. As depicted in Table 1, the results obtained from both the pretest and posttest display a generally favorable trend in students' perceptions of their knowledge regarding Pili's SD. Specifically, statements related to the economic advantages of promoting the Pili business (K1) and the environmental consequences of planting Pili trees (K4) indicated an increase in the number of students who agreed or strongly agreed during the posttest, implying a heightened comprehension and appreciation of these facets. However, perceptions concerning the potential for women's empowerment (K3) and alignment with cultural values (K5) remained relatively stable over time.

Table 1. Students' Perception of their Knowledge on SD of Pili

Statement	Pretest *f*(%)				Posttest *f*(%)			
	4	3	2	1	4	3	2	1
K1	12(32)	22(58)	3(8)	1(3)	22(58)	15(39)	1(3)	-
K2	15(39)	22(58)	1(3)	-	30(79)	8(21)	-	-
K3	16(42)	21(55)	1(3)	-	20(53)	18(47)	-	-
K4	25(66)	13(34)	-	-	29(76)	9(24)	-	-
K5	25(66)	13(34)	-	-	27(71)	11(29)	-	-
K6	15(39)	20(53)	2(5)	1(3)	23(61)	15(39)	-	-
K7	22(58)	16(42)	-	-	28(61)	10(26)	-	-
K8	26(68)	12(32)	-	-	30(79)	8(21)	-	-
Total	**156(51.3)**	**139(45.7)**	**7(2.3)**	**2(.7)**	**209(68.8)**	**94(30.9)**	**1(.3)**	**-**

Legend: 4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly agree

The positive shifts observed in students' perceptions of Pili's SD can be attributed to the intervention involving the utilization of the I-STEM-PBL module. This approach provided students with a structured framework to delve into various dimensions of SD and Pili's role within it. Through active participation in PBL activities, students gained practical experience, collaborated on projects, and critically analyzed diverse aspects of Pili's SD. This active learning approach likely contributed to the enhanced comprehension and favorable perception among students regarding the potential benefits of Pili, encompassing economic opportunities, environmental conservation, and cultural preservation.

Another significant dimension to consider is the students' attitudes, encompassing their emotional responses and sentiments regarding Pili's SD. Table 2 presents the outcomes pertaining to students' perceptions of their attitudes toward Pili's SD. The findings illuminate the students' viewpoints regarding their attitudes toward Pili's SD. The outcomes reveal a spectrum of attitudes related to various facets of Pili's sustainability. Notably, there was an upswing in the percentage of students expressing happiness and admiration during the posttest, particularly in response to statements concerning the recognition of Pili's significance in preserving Bicol's culture (A1), the implementation of more stringent laws to safeguard Pili trees (A4), investments in Pili for poverty alleviation (A5), and the government's promotion of renewable energy in Pili production (A7). Conversely, there was a slight increase in the percentage of students expressing frustration regarding the absence of zero-waste practices by Pili manufacturers (A2) and the exploitation of Pili resources (A6). These findings suggest that the integration of the I-STEM-PBL module and pedagogical approach likely played a role in shaping students' attitudes toward Pili's SD, fostering positive emotions and concerns related to conservation and socio-economic dimensions.

Table 2. Students' Perception of their Attitudes on Sustainable Development of Pili

Statements	Pretest f(%)				Posttest f(%)			
	4	**3**	**2**	**1**	**4**	**3**	**2**	**1**
A1	25(66)	13(34)	-	-	31(82)	7(18)	-	-
A2	13(34)	20(53)	5(13)	-	14(37)	21(55)	3(8)	-
A3	12(32)	23(61)	3(8)	-	15(39)	61(23)	-	-
A4	25(66)	13(34)	-	-	24(63)	14(37)	-	-
A5	20(53)	16(42)	1(3)	1(3)	26(68)	12(32)	-	-
A6	12(32)	25(66)	1(3)	-	16(42)	22(58)	-	-
A7	27(71)	10(26)	1(3)	-	26(68)	12(32)	-	-
A8	16(42)	20(53)	2(5)	-	19(50)	19(50)	-	-
Total	**150(49.3)**	**140(46.1)**	**13(4.3)**	**1(.3)**	**171(56.3)**	**168(55.3)**	**3(1)**	**-**

Legend: 4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly agree

Another crucial aspect to consider is the students' actions and conduct, encompassing the behaviors and practices associated with Pili's sustainable development (SD), which are influenced by both personal and environmental factors. Table 3 presents an overview of the students' self-perceptions regarding their behaviors in relation to Pili's SD.

Table 3. Students' Perception of their Behaviors on Sustainable Development of Pili

Statements	Pretest f(%)				Posttest f(%)			
	4	**3**	**2**	**1**	**4**	**3**	**2**	**1**
B1	1(3)	20(53)	15(39)	2(5)	9(24)	26(68)	2(5)	1(3)
B2	18(47)	19(50)	1(3)	-	20(53)	17(45)	1(3)	-
B3	-	2(5)	27(71)	9(24)	1(3)	11(29)	23(61)	3(8)
B4	1(3)	17(45)	15(39)	5(13)	9(24)	18(47)	11(29)	-
B5	8(21)	24(63)	5(13)	1(3)	15(39)	20(53)	3(8)	-
B6	-	3(8)	20(79)	5(13)	-	10(26)	24(63)	4(11)
B7	9(24)	21(55)	5(13)	3(8)	22(58)	12(32)	4(11)	-
B8	-	8(21)	25(66)	5(13)	3(8)	11(29)	21(55)	3(8)
Total	**37(12.2)**	**114(37.5)**	**113(37.2)**	**30(9.9)**	**79(26)**	**125(41.1)**	**89(29.3)**	**11(3.6)**

Legend: 4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly agree

Table 3 illustrates diverse responses regarding the students' involvement in actions and practices pertaining to Pili's sustainability. Significantly, there was an increase in the percentage of students who reported using Pili as an example in classroom discussions (B1), contemplating ways to protect Pili from environmental degradation (B5), engaging in conversations concerning how Pili can contribute to poverty alleviation (B4), and delving into studies focused on repurposing Pili waste into valuable materials (B7).

However, there were relatively modest percentages of students participating in seminars focused on Pili's sustainable development (B3), collaborating with government authorities to plant Pili trees (B6), and volunteering for organizations dedicated to advancing Pili's SD (B8). These findings indicate that while the implementation of I-STEM-PBL modules may have positively influenced specific behaviors, there is room for improvement in terms of students' active engagement in various facets of Pili's sustainable development.

To conduct a comprehensive analysis of the pretest and posttest results pertaining to students' KAB, the researcher utilized the Wilcoxon signed rank test. Table 4 presents the outcomes of the Wilcoxon signed rank test, offering valuable insights into the statistical significance of the observed changes in students' KAB indicators.

Table 4. Difference of Pretest and Posttest in relation to Students’ KAB toward SD of Pili

KAB Domains	**Negative ranks**			**Positive ranks**			**Ties**	**Z**	***P*-value**	**Effect size (Cohen’s *d*)**
	N	**Mean**	**Sum**	**N**	**Mean**	**Sum**				
Knowledge	22	20.23	445	12	12.5	150	4	.365	.011	0.078
Attitudes	36	19.35	696.5	1	6.5	6.5	1	.730	< .001	0.122
Behaviors	37	20	740	1	1	1	0	.000	< .001	0.000
Overall	**67**	**59**	**3977**	**36**	**38.31**	**1379**	**11**	**.314**	**< .001**	0.038

Table 4 exhibits the disparities between the pretest and posttest scores regarding students' KAB concerning Pili's SD. The findings suggest substantial enhancements in students' knowledge ($p < .05$), attitudes ($p < .001$), and behaviors ($p < .001$) pertaining to Pili's SD, as indicated by the statistically significant p-values ($p < .001$). These results affirm that the intervention employing the I-STEM-PBL module effectively boosted students' KAB, underscoring its efficacy in enhancing their understanding, attitudes, and actions concerning Pili's SD.

To gauge the magnitude of this impact, Cohen's d was computed. The calculated Cohen's d values for each KAB domain in Table 4 delineate the effect size or magnitude of the observed differences between the pretest and posttest scores. For Knowledge, the Cohen's d value stands at 0.078, signifying a small effect size, implying a modest impact of the intervention on students' knowledge regarding Pili's SD. Similarly, for Attitudes, the Cohen's d value is 0.122, representing a small effect size, indicating a slight shift in students' attitudes resulting from the intervention, albeit with a relatively small impact. In contrast, for Behaviors, the Cohen's d value registers at 0.000, suggesting no effect size or noticeable change in students' behaviors associated with Pili's SD. This implies that the intervention did not significantly influence students' behaviors. In summary, the overall Cohen's d value for the entire KAB assessment is 0.038, indicating a small effect size. This indicates that the I-STEM-PBL module intervention had a generally modest impact on students' KAB metrics regarding Pili's SD.

The researcher evaluated each student's KAB level based on their individual OSISDeP scores, categorizing them into three tiers according to the percentage ranges: (a) scores below 60% were classified as poor, (b) scores ranging from 60% to 80% indicated moderate, and (c) scores exceeding 80% to 100% denoted high. Table 5 presents the distribution of students across these KAB levels.

Table 5. Level of Students KAB toward Sustainable Development of Pili

Dimension	Level	Pretest		Posttest	
		Frequency	Percentage	Frequency	Percentage
Knowledge	Poor	0	0	0	0
	Moderate	4	11	1	3
	High	34	89	37	97
Attitudes	Poor	0	0	0	0
	Moderate	5	13	1	3
	High	33	87	37	97
Behaviors	Poor	4	11	0	0
	Moderate	30	78	21	55
	High	4	11	17	45

Table 5 unveils intriguing insights into the connections among the KAB domains. In the pretest phase, noteworthy associations were observed between Knowledge and Behaviors, as well as Knowledge and Attitudes. These findings suggest a correlation between students' comprehension and their inclinations towards behavior and attitude. However, during the posttest phase, a significant association was only detected between Knowledge and Attitudes. This implies that the intervention, particularly the incorporation of I-STEM-PBL modules, may have had a more pronounced effect on aligning students' knowledge and attitudes, rather than directly influencing their knowledge and behaviors. This underscores the need for additional efforts to bridge the gap between knowledge and behaviors in the posttest results.

These outcomes could potentially be influenced by the limitations of the environment in which students conducted the I-STEM-PBL module. It is plausible that students lacked exposure to real-world community settings where they could actively apply their knowledge and skills. This absence of practical experience within the community might have constrained their ability to fully translate their knowledge into sustainable behaviors. To further amplify the effectiveness of the intervention, future implementations could contemplate incorporating opportunities for students to engage directly with the community. Such an approach would allow them to apply their learning in authentic, real-life scenarios and cultivate a deeper comprehension of sustainable development principles. This form of community engagement could provide a more comprehensive learning experience and potentially bridge the divide between theoretical knowledge and practical application among the students.

In summary, the introduction of I-STEM-PBL modules has yielded positive outcomes regarding students' KAB concerning Pili's sustainable development. The posttest results indicated substantial enhancements in all three dimensions, signifying that the intervention successfully enriched students' understanding, and perceptions of SD principles related to Pili. Nevertheless, it is crucial to acknowledge that room for improvement exists by addressing the limitations identified in this study. By affording students opportunities to implement their knowledge within real-world community settings, the intervention can effectively bridge the chasm between theoretical knowledge and practical implementation. Additionally, continuous assessment and fine-tuning of the intervention can optimize its efficacy in promoting sustainable practices among the students.

Discussion and Implications

The implementation of the I-STEM-PBL-ESD instructional framework (Funa, 2023; Funa et al., in press) led to positive shifts in students' knowledge regarding Pili's SD. Notably, students exhibited an improved understanding of the economic advantages of promoting the Pili business and the environmental consequences of planting Pili trees. This suggests that the framework effectively enhanced their comprehension of the intricate relationships between sustainable practices, economic viability, and environmental conservation. These findings align with the principles of education for sustainable development (ESD), emphasizing the importance of cultivating students' knowledge about sustainability issues (Buckler & Creech, 2014). By utilizing an active learning approach embedded in PBL activities, the I-STEM-PBL-ESD framework engaged students in critical inquiry and problem-solving, which contributed to a deeper understanding of the multifaceted aspects of SD. These results underscore the potential of the framework to foster knowledge acquisition in the context of sustainability education.

The intervention also had a significant impact on students' attitudes toward Pili's SD. Post-implementation, students expressed more positive sentiments, particularly regarding the recognition of Pili's significance in preserving Bicol's culture, the need for stringent laws to safeguard Pili trees, and the potential of Pili for poverty alleviation. These shifts in attitudes reflect a growing sense of appreciation for the cultural, environmental, and socio-economic dimensions of sustainable Pili cultivation. The positive changes in attitudes among students can be attributed to the learner-centered and action-oriented nature of the I-STEM-PBL-ESD framework (Funa et al., 2023). Through collaborative problem-solving and engagement with real-world sustainability challenges, students had opportunities to develop a sense of agency and responsibility, which likely influenced their attitudes toward sustainable practices (Buckler & Creech, 2014). These findings emphasize the potential of such pedagogical approaches in instilling values and attitudes conducive to sustainability.

While the intervention had a notable impact on knowledge and attitudes, the changes in students' behaviors were more modest. Students reported increased participation in certain behaviors, such as using Pili as an example in classroom discussions and contemplating ways to protect Pili from environmental degradation. However, there was limited engagement in behaviors such as collaborating with government authorities to plant Pili trees or volunteering for organizations dedicated to advancing Pili's SD. The relatively small effect size in the behaviors domain suggests that the translation of knowledge and attitudes into concrete actions remains a challenge. This outcome underscores the need for educational interventions to not only inform and shape attitudes but also provide students with opportunities for practical application in real-world contexts (Burns et al., 2019). Community engagement initiatives, internships, or service-learning experiences could bridge this gap, allowing students to actively participate in sustainability efforts and observe the tangible outcomes of their actions.

The findings of this study have several significant implications for both educational practices and broader sustainability initiatives. The study underscores the importance of innovative pedagogical approaches like the I-STEM-PBL-ESD framework in addressing complex sustainability challenges. Educational institutions may draw upon this model to equip students with the knowledge, attitudes, and behaviors required to contribute to global sustainability goals, including those outlined in the United Nations Sustainable Development Goals (SDGs). By integrating such learner-centered and action-oriented approaches into curricula, educational systems may foster a generation of proactive and informed global citizens committed to sustainability.

Within the Philippines, the implications are particularly pertinent given the country's rich biodiversity and its commitment to SD. The Philippines, as an archipelagic nation, faces unique challenges and opportunities in terms of environmental conservation, economic growth, and cultural preservation. The positive shifts observed in students' KAB concerning Pili's SD are indicative of the potential to revitalize traditional livelihoods, such as Pili farming, in alignment with sustainable practices. These outcomes may inform policy decisions related to sustainable agriculture, environmental protection, and cultural heritage preservation in the Philippines.

Educational institutions may benefit from reevaluating and redesigning their curricula to incorporate learner-centered and action-oriented approaches similar to the I-STEM-PBL-ESD framework. This approach has demonstrated its capacity to effectively enhance students' knowledge and attitudes concerning sustainability, underscoring the importance of innovative pedagogical methods (Funa et al., 2023). Teachers, as crucial facilitators of learning, should receive training and support in implementing such approaches, recognizing the pivotal role they play in shaping students' sustainability perspectives (Barth et al., 2017).

Furthermore, educational programs may consider integrating community engagement opportunities into their sustainability education initiatives. The study's results highlight the need to bridge the gap between theoretical knowledge and practical application by involving students in real-world sustainability efforts. Initiatives such as community-based projects, internships, or service-learning experiences could provide students with hands-on opportunities to apply what they have learned, fostering a deeper understanding of SD principles, and promoting active participation in sustainable practices.

Continuous assessment and fine-tuning of educational interventions are also essential. Regular evaluations may help optimize the effectiveness of sustainability-focused pedagogical approaches, ensuring that they remain aligned with evolving educational goals and student needs. Moreover, it is imperative that the policymakers and educational authorities recognize the importance of sustainability education and allocate resources to support innovative approaches that enhance students' knowledge and skills related to SD.

Limitations of the Study

While this study has shed light on the impact of the I-STEM-PBL-ESD framework on students' KAB related to SD, it is essential to acknowledge its limitations. The absence of practical community engagement opportunities and the relatively small sample size limit the generalizability of the findings. Future research may address these constraints and consider long-term assessments of the framework's effects. Despite these limitations, the study's significance lies in its contribution to the field of sustainability education. It highlights the potential of innovative pedagogical approaches to transform students into active participants in SD initiatives. By fostering knowledge acquisition, shaping positive attitudes, and offering opportunities for practical application, this study underscores the crucial role of education in addressing sustainability challenges. It provides valuable insights for educators, policymakers, and sustainability advocates seeking effective strategies to empower future generations with the knowledge and skills needed to drive SD forward.

Conclusions and Recommendations

This study has explored the transformative potential of the I-STEM-PBL-ESD framework in enhancing students' KAB related to SD, with a specific focus on Pili (C. ovatum) in the Bicol region, Philippines. The findings suggest that the implementation of the I-STEM-PBL approach positively impacted students' KAB regarding Pili's SD, signifying its efficacy as an educational strategy. Notably, students demonstrated significant improvements in their knowledge and attitudes, albeit with a relatively small effect size, following their engagement with the I-STEM-PBL-ESD framework. However, the study revealed limited direct influence on students' behaviors, indicating the need for further strategies to bridge the gap between knowledge and action.

The implications of this study extend beyond the classroom, offering valuable insights for educators, policymakers, and stakeholders in sustainability education. First and foremost, the study underscores the importance of innovative pedagogical approaches like I-STEM-PBL-ESD in equipping students with the knowledge and attitudes necessary to engage actively in SD initiatives. By fostering a deeper understanding of sustainability principles and cultivating positive attitudes toward environmental and socio-economic issues, this framework can empower the next generation to become agents of change in addressing pressing sustainability challenges.

Furthermore, this study highlights the need for continued refinement and expansion of the I-STEM-PBL-ESD framework. Future research should explore ways to strengthen the framework's impact on students' behaviors, potentially by incorporating practical, community-based projects that allow students to apply their knowledge and skills in real-world contexts. Additionally, the scalability of the framework should be examined to ensure its accessibility to a broader range of educational institutions and settings.

In practical terms, educators need to consider integrating I-STEM-PBL-ESD approaches into their curricula, particularly in STEM-focused disciplines. Professional development opportunities for teachers should be offered to ensure effective implementation. Policymakers should also recognize the value of such innovative pedagogies in achieving sustainable development goals and allocate resources accordingly.

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