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Investigating Culinary Vocational Students' Sustainability Action through Learning of Physical and Chemical Changes

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Abstract: Vocational education is pivotal in advancing the Sustainable Development Goals (SDGs), particularly SDG 12, which emphasizes responsible consumption and production. However, preliminary studies indicate that sustainability action competence among culinary vocational high school students remains relatively low. This study aims to investigate the level of sustainability action competence among culinary vocational school students and examine the role of science education, specifically changes in matter, in supporting this competence. An exploratory sequential mixed-methods design was employed. Quantitative data were collected using a questionnaire based on SDG 12 indicators, validated by three experts and tested for reliability, yielding Cronbach's alpha values ranging from 0.714 to 0.814. Quantitative data were analyzed using the Kruskal-Wallis test to identify differences across domains, and Spearman correlation analysis to examine interrelationships among competence domains. Subsequently, semi-structured interviews were conducted with science teachers and students to explore how the topic of changes in matter is integrated into sustainable culinary practices. Findings reveal that students scored high in the cognitive domain (68%), but considerably lower in the socio-emotional (40%) and behavioral (30%) domains. Correlational analysis showed significant relationships among all domains, with the strongest correlation between cognitive and behavioral domains ($\rho = 0.878$; $p < 0.001$), indicating a notable gap between knowledge and sustainability action. Integrating the concept of substance changes with sustainable culinary practices offers promising potential for fostering sustainability competence. The implications of this study underscore the urgent need to develop more contextual and applied science learning materials, notably on changes in matter, that explicitly integrate SDG 12 principles into culinary practices. Science education interventions are strongly recommended to incorporate Education for Sustainable Development (ESD) approaches through Project-Based Learning. Such pedagogical strategies can empower students to implement sustainable actions daily and position them as change agents for building a sustainable future.

Keywords: science education, vocational education, sustainability action, ESD, SDG 12.

▪ INTRODUCTION

Education is fundamental to sustainable development, and vocational education is critical in promoting global sustainability (Y. Liu & Chen, 2025). Vocational education strategically supports realizing the Sustainable Development Goals (SDGs), particularly SDG 12, which emphasizes responsible consumption and production (UNESCO, 2020). In this context, vocational students are expected not only to master technical skills but also to internalize sustainability-related attitudes and values reflected in their everyday actions in the workplace. This aligns with the view of Gemil et al. (2024), who assert that vocational education is essential in producing competent workforces, fostering economic sustainability, and contributing directly to achieving the SDGs.

Nevertheless, several challenges persist, including limited resources, time constraints, and the need for specialized teacher training to effectively integrate

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sustainability content into vocational curricula in various countries (Lei & Abidin, 2024). These barriers contribute to low awareness and engagement among vocational students in sustainability issues, particularly within the culinary industry, which significantly contributes to food waste and energy consumption (FAO, 2024).

Education for Sustainable Development (ESD) is an educational approach promoted to support the achievement of the Sustainable Development Goals (SDGs) through the education sector (UNESCO, 2017). ESD empowers learners to make informed and responsible decisions that ensure environmental integrity, economic viability, and a just society (Taimur & Sattar, 2019). According to Liu et al. (2023), ESD plays a vital role in education, particularly in fostering students' awareness and behaviour toward environmental issues.

According to the UNESCO (2017) framework, ESD-oriented learning should present content directly linked to one or more SDG targets. UNESCO (2017) also emphasizes that ESD is not limited to knowledge transmission but includes developing awareness and promoting sustainability-related actions. For students to engage in meaningful sustainability actions, they must understand sustainability deeply, including its significance and challenges. Once this foundational knowledge is established, students are more likely to develop personal awareness and a sense of responsibility, leading to active participation in sustainability efforts. Thus, the cognitive and affective domains are essential precursors to behavioural engagement in sustainability. Lambini et al. (2021) argue that integrating ESD into vocational education is crucial to preparing young generations for the future's complex environmental and social challenges.

SDG 12 emphasizes reducing food waste, promoting resource efficiency, and adopting sustainable lifestyles. In the culinary sector, this includes selecting sustainable ingredients, proper food waste management, energy reduction during food preparation, and consumer education (UNEP, 2022). Integrating SDG 12 principles into vocational curricula supports national education policies and cultivates graduates who are competent and aware of their social and environmental responsibilities.

Various ESD-based interventions have been developed, such as Project-Based Learning (Ariza & Olatunde-Aiyedun, 2023; Bramwell-Lalor, Kelly, et al., 2020; Derler et al., 2020; Li et al., 2022; Rahmayanti et al., 2021), STEM-Problem Based Learning (Abdurrahman et al., 2023), Cooperative Learning (Lozano et al., 2022), ESD-based POE (Predict, Observe, and Explain) Learning (Fatimah et al., 2023), and Experiential Learning (Chaikovska et al., 2021). However, the intersection between science education, particularly physical and chemical changes and the attainment of SDG 12 in vocational education remains underexplored, making this study both theoretically significant and practically relevant.

Physical and chemical changes in science education, particularly chemistry, offer a highly relevant context for culinary vocational students. Processes such as caramelization, fermentation, protein denaturation, and emulsion formation are concrete examples of physical and chemical transformations during cooking activities (Aguilera & Moreno, 2021). By integrating these contexts into instruction, students gain a deeper understanding of scientific concepts and recognize their practical implications for food quality, safety, and sustainability. Teaching physical and chemical changes within the sustainability framework, such as zero-waste cooking, using local ingredients, and energy efficiency,

can foster ecological awareness and responsible behaviour among students in their culinary practices (Özilgen & Raton, 2019).

Sustainability competence refers to the ability to apply knowledge, skills, and attitudes in making decisions and taking actions that balance environmental, economic, and social dimensions (Redman & Wiek, 2021; Wiek et al., 2011). Within the Education for Sustainable Development (ESD) framework, this competence is essential for empowering learners to become change agents capable of designing sustainable solutions (UNESCO, 2020).

However, there remains a significant gap in research that integrates science education, particularly matter changes, into sustainability-oriented culinary practices. While numerous studies on ESD in vocational education have primarily focused on curriculum development, teacher training, or institutional policy frameworks, few have thoroughly examined the practical application of scientific concepts in fostering sustainability actions within culinary contexts. Yet, culinary practices offer a highly contextualized and tangible platform for cultivating sustainability competencies through scientifically grounded approaches. Therefore, this study addresses a critical need to explore how learning about substance changes can enhance vocational students' sustainability action competence, serving as a strategic effort to advance SDG 12 implementation within vocational education settings.

Behaviour encompasses applying sustainability knowledge through systems thinking, anticipatory and critical reflection, and concrete actions that support sustainability (Sammalisto et al., 2016). According to Oinonen and Paloniemi (2023), behaviour refers to the actions undertaken by individuals or groups to promote sustainability. Amaral et al. (2021) further define sustainable behaviour as initiatives aimed at minimizing the environmental impact of human activities, with a focus on efficient resource use and greenhouse gas emission reduction. These actions vary in terms of effort, commitment, and public visibility. Sass et al. (2024) suggest that students' sustainability-related behaviours can be enhanced through ESD-oriented learning.

Sustainable behaviour is crucial in achieving the Sustainable Development Goals, particularly SDG 12, which emphasizes sustainable production and consumption patterns. This is supported by the findings of Almendros et al. (2023), who reported that ESD-oriented learning focused on SDG 12 could enhance students' knowledge and awareness regarding sustainable production and consumption while highlighting education's critical role in fostering sustainability-related behaviours. However, there remains a lack of studies that specifically integrate science learning, particularly the topic of chemical changes, within culinary practices aimed at strengthening sustainability competencies among vocational students. In Indonesia as a developing country facing challenges in integrating the SDGs into vocational curricula, the urgency for such research becomes even more evident. Therefore, this study is significant in exploring how does instruction on physical and chemical changes within culinary practices influence the sustainability action competence of vocational high school students majoring in culinary.

▪ METHOD

Participants

The research subjects comprised 10 tenth-grade students majoring in culinary at a vocational high school in Nganjuk Regency. The school was selected based on

accessibility, existing collaboration with the researchers, and its implementation of a culinary vocational curriculum aligned with national education standards. A purposive sampling strategy was employed to select students who had completed prior physical and chemical changes instruction. This sampling approach was intended to ensure that the selected participants possessed basic conceptual exposure relevant to the study objectives. Although the sample size was limited, the selection was based on initial exploratory considerations to identify the contextual needs for ESD interventions.

Research Design and Procedures

This study employed an exploratory sequential mixed-methods design, integrating quantitative and qualitative data. This approach was chosen to provide a more comprehensive understanding of students' sustainability actions, capturing statistical trends and more profound insights through interviews. Data collection, comprising questionnaires and interviews, was conducted in a single session before implementing the ESD-oriented instructional intervention.

Instrument

Sustainability Actions Questionnaire

The sustainability action questionnaire consists of both positive and negative statements with binary response options: "Yes or No". For positive statements, a "Yes" response is scored as 1 and "No" as 0. Conversely, for negative statements, a "Yes" response is scored as 0 and "No" as 1. The indicators of the sustainability action questionnaire were developed based on the Learning Objectives of SDG 12 outlined in UNESCO (2017), including:

Cognitive	1)	The learner understands how individual lifestyle choices influence social, economic and environmental development.
	2)	The learner understands production and consumption patterns and value chains and the interrelatedness of production and consumption (supply and demand, toxics, CO_2 emissions, waste generation, health, working conditions, poverty, etc.).
	3)	The learner knows about strategies and practices of sustainable production and consumption.
Socio-emotional	1)	The learner is able to communicate the need for sustainable practices in production and consumption.
	2)	The learner is able to encourage others to engage in sustainable practices in consumption and production.
	3)	The learner is able to envision sustainable lifestyles.
Behavioural	1)	The learner is able to plan, implement and evaluate consumption-related activities using existing sustainability criteria.
	2)	The learner is able to promote sustainable production patterns

The sustainability action questionnaire underwent rigorous validation to ensure its content and construct validity. Initially, the instrument was evaluated by three experts in science education and ESD to assess the clarity, relevance, and alignment of items with the learning objectives of SDG 12 as defined by UNESCO (2017) and matter changes. Based on their feedback, revisions were made. Subsequently, construct validation was conducted through a limited pilot test. The collected data were analyzed to examine item

validity and reliability. Nine of the 10 cognitive items were valid, with a Cronbach's alpha value of 0.814, indicating good reliability. Nine of the 10 socio-emotional items were valid, with a Cronbach's alpha value of 0.780, indicating good reliability. Six of the nine Behavioral items were valid, with a Cronbach's alpha value of 0.714, indicating acceptable reliability. Data collection was based solely on the valid items, resulting in 24 items.

Semi-structured Interviews

Semi-structured interviews were conducted with in a session with two science teachers and two randomly selected tenth-grade culinary students to gain a deeper understanding of science education at the school, particularly regarding physical and chemical changes and their connection to sustainability issues. All interviews were conducted face-to-face and manually documented through field notes by the researcher, each lasting 15 minutes.

The interviews explored several key aspects , including educators' and students' understanding of the SDGs and ESD, and the extent to which these concepts are recognized and internalized within the school context. The discussions also focused on implementing science education approaches, particularly regarding physical and chemical changes, and how these topics are integrated into classroom practices. Furthermore, the interviews examined how the concepts of physical and chemical changes are connected to everyday life contexts, such as food processing activities. Finally, the dialogue addressed whether sustainability principles, such as food waste management and responsible consumption, have been incorporated into science teaching practices.

Data Analysis

Quantitative Data

The results of the sustainability action questionnaire were analyzed using a scoring equation, with scoring categories adapted from Fajri et al. (2023), as shown in Table 1. Each response was scored based on the type of statement: for positive statements, a yes was scored as 1 and a no as 0; for negative statements, the scoring was reversed. The total score was then converted into a percentage using the formula:

$$Percentage\ score = \frac{Total\ score\ obtained}{Maximum\ possible\ score}\ x\ 100\%$$

The quantitative data from the sustainability action questionnaire were first tested for normality using the Shapiro-Wilk test to determine the appropriate statistical analysis. Based on the results, the Kruskal–Wallis test was employed to examine significant differences among cognitive, socio-emotional, and behavioral domains, as the data did not meet the assumption of normal distribution. Furthermore, Spearman's rank-order correlation was used to analyze the relationships among the three domains, as it is suitable for ordinal and non-parametric data. All statistical analyses were performed using IBM SPSS Statistics version 27.

Table 1. Sustainability Action Score Categories

Score (%)	Category
81 – 100	Very High
61 – 80	High
41 – 60	Moderate
21 – 40	Low
0 – 21	Very Low

Qualitative Data

The qualitative data analysis in this study followed the framework outlined by Miles and Huberman (2014), consisting of three sequential stages: (1) Data reduction, data from semi-structured interviews were filtered and coded using NVivo 12 Plus. The coding process involved identifying recurring phrases and grouping them into parent and child nodes representing major themes (e.g., Student Practices, Teacher Readiness, Curriculum, and SDGs Integration); (2) Data display, in which reduced data were visualized using hierarchical diagrams and word clouds to illustrate emerging patterns and thematic clusters; (3) Conclusion drawing and verification, the researcher synthesized findings and cross-checked them with the initial objectives to formulate meaningful conclusions.

To ensure validity of qualitative data, multiple strategies were applied: (1) Data triangulation, by comparing responses between teachers and students; (2) Methodological triangulation, by integrating qualitative data with questionnaire findings to support interpretation; (3) Peer debriefing, where a qualitative research colleague reviewed themes and codes to reduce bias; (4) Prolonged engagement and persistent observation, as data were collected over multiple sessions through careful field note-taking.

The qualitative data were obtained through semi-structured interviews, manually recorded as field notes due to the absence of audio recordings. The interviews were conducted after completing the questionnaire, allowing for a more profound exploration of student and teacher perceptions about the quantitative trends. Although observation and document analysis were not applied in this study, interview data provided sufficient depth for thematic exploration.

▪ RESULT AND DISSCUSSION

Students' Sustainability Action

Figure 1. Students' sustainability competency scores across cognitive, socio-emotional, and behavioral domains in culinary vocational schools. The cognitive domain shows the highest average score (68%, high category), indicating a strong conceptual understanding of sustainability. In contrast, socio-emotional (40%) and behavioral (30%) domains remain low, suggesting limited affective engagement and minimal translation of knowledge into sustainable culinary practices.

This phenomenon underscores the existence of a fragmented hierarchy in sustainability learning, where knowledge acquisition is not accompanied by the development of relevant attitudes and behaviours (Vare & Scott, 2020). Several possible causes can explain this gap. First, the learning methods predominantly used are still teacher-centered and emphasize cognitive mastery over participatory and affective engagement. Second, the lack of experiential learning activities such as simulations, reflective journaling, or real-life sustainability projects limits students' opportunities to

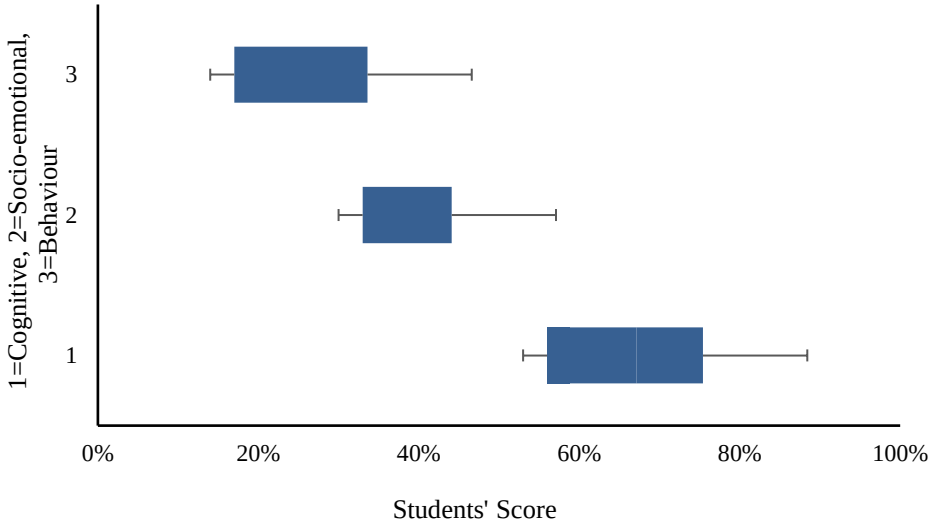

Figure 1. Boxplot of students' scores in cognitive, socio-emotional, and behavioral domains of sustainability competencies

internalize knowledge into meaningful attitudes and sustained actions. Third, teachers reported constraints in time and resources, as well as limited training on ESD, which further reduces the effectiveness of affective-behavioral learning components.

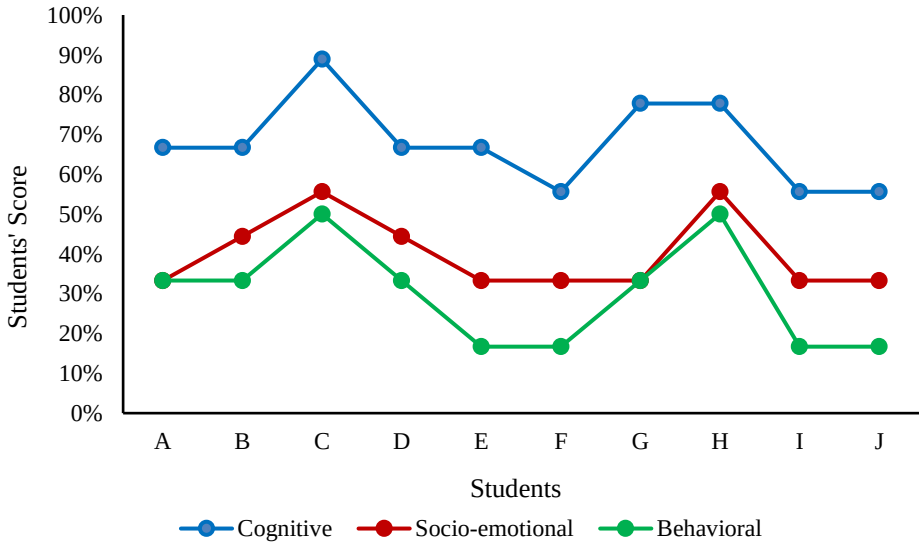

Figure 2. Students' score in cognitive, socio-emotional and behavioral

Figure 2 compares students' scores across three domains of sustainability competencies: cognitive, socio-emotional, and behavioral. The cognitive domain exhibits the highest and most consistent scores, ranging from approximately 60% to 90%. This indicates that students demonstrate relatively strong conceptual understanding of sustainability-related topics delivered during instruction. In contrast, the behavioral domain shows the lowest scores, with most students scoring below 40%, and some as low

as 10–20%. The socio-emotional domain presents a more fluctuating trend, with moderate scores that vary across individual students.

These findings reveal a significant gap between students' knowledge (cognitive domain) and their actual sustainable practices (behavioral domain), often referred to as the "conversion gap." Although students demonstrated a reasonably sound conceptual understanding of sustainability, this knowledge has not been effectively translated into empathetic attitudes or consistent pro-sustainability behaviors. This suggests that sustainability education in Indonesian vocational high schools remains primarily cognitive and informative rather than transformative and participatory, as emphasized in the Education for Sustainable Development (ESD) framework by UNESCO (2017). According to the sustainability competence model Wiek et al. (2011) developed, emotional engagement and action-oriented skills are prerequisites for translating sustainability knowledge into meaningful behavior change.

Furthermore, SDG 12 demands a paradigm shift from unsustainable consumption and production patterns toward more responsible lifestyles. Achieving this transformation requires more than cognitive awareness of recycling or waste management; it calls for a deep sense of personal responsibility and the ability to apply sustainability principles in real-life contexts, particularly daily culinary practices. However, the absence of experiential learning opportunities, such as zero-waste cooking, food waste management, and organic composting, limits the practical impact and contextual relevance of sustainability learning in vocational culinary education.

This pattern is consistent with the findings of Almendros et al. (2023) and Sass et al. (2024), who assert that sustainability education emphasizing knowledge alone often fails to trigger meaningful student action. Therefore, ESD-based instructional interventions must be intentionally designed to build knowledge and cultivate emotional awareness and active student engagement through experiential learning. For example, instruction on physical and chemical changes in food can be strategically linked to sustainable culinary practices, such as fermentation, organic waste separation, and energy-efficient cooking techniques.

International literature further supports these findings, which underscore the necessity of integrating cognitive, socio-emotional, and behavioral domains in ESD. UNESCO (2017) argues that effective sustainability education equips learners with the knowledge, values, attitudes, and skills required to make responsible decisions and act accordingly. Wiek et al. (2011) emphasize that without emotional involvement and action-based competencies, knowledge remains passive and fails to foster behavioral transformation. Similarly, OECD (2024) highlights the role of socio-emotional skills, such as empathy and responsibility, in promoting prosocial and environmentally conscious behaviors. Studies by Kioupi, V., & Voulvoulis, N. (2019) and Zitouni, A., & Baelo, R. (2023) also demonstrate that reflective, transformative pedagogies and the contextual integration of SDG 12 can significantly enhance students' sustainability awareness and engagement. Thus, this study's low performance in the socio-emotional and behavioral domains reinforces the urgent need for holistic, context-driven, and experience-based ESD interventions in vocational settings.

While Figure 2 visually demonstrates the disparities among students' cognitive, socio-emotional, and behavioral competencies, it is essential to determine whether these differences are statistically significant. To this end, we conducted a Shapiro-Wilk

normality test for each domain. The results indicated that the socio-emotional domain ($p = 0.001$) and the behavioral domain ($p = 0.025$) deviated significantly from a normal distribution, while the cognitive domain was only marginally normal ($p = 0.055$). Given these findings and the relatively small sample size ($N = 10$ per group), the assumptions of normality required for parametric tests were not met.

Consequently, a non-parametric Kruskal-Wallis test was employed to examine whether the differences in students' scores across the three domains were statistically significant. The analysis produced a Kruskal-Wallis H value of 20.589 with 2 degrees of freedom and an asymptotic significance value of $p < 0.001$, indicating a highly significant difference among the three domains. These statistical results corroborate the descriptive trends in Figure 2 and validate that the observed disparities are not attributable to chance.

Together, the descriptive and inferential analyses confirm that vocational students tend to excel in understanding sustainability concepts (cognitive) but struggle with internalizing these concepts emotionally (socio-emotional) and implementing them behaviorally (behavioral). This disconnect reinforces the need for transformative pedagogical interventions integrating experiential learning and emotional engagement, particularly within vocational culinary education.

The results of the Spearman correlation analysis are presented in Table 2. The findings indicate a significant relationship among the three domains of sustainability competencies. First, a positive and statistically significant correlation was found between the cognitive and socio-emotional domains, with a coefficient of $\rho = 0.650$ and $p = 0.042$, suggesting that higher cognitive competence is associated with greater socio-emotional awareness among students. Second, the correlation between cognitive and behavioral domains was notably strong, with $\rho = 0.878$ and $p < 0.001$. This result implies that conceptual understanding of sustainability issues is closely linked to the implementation of sustainable behaviors in educational settings. Third, the socio-emotional and behavioral domains also showed a significant correlation, with $\rho = 0.825$ and $p = 0.003$, indicating that affective and empathetic aspects play a vital role in encouraging concrete actions toward sustainability.

Table 2. Correlation among the domains of sustainability competencies

			Cognitive	**Socio-emotional**	**Behavioral**
Spearman's rho	Cognitive	Correlation Coefficient	1.000	.650*	.878**
		Sig. (2-tailed)	.	.042	<.001
		N	10	10	10
	Socio-emotional	Correlation Coefficient	.650*	1.000	.825**
		Sig. (2-tailed)	.042	.	.003
		N	10	10	10
	Behavioral	Correlation Coefficient	.878**	.825**	1.000
		Sig. (2-tailed)	<.001	.003	.
		N	10	10	10

Factors such as intrinsic motivation, environmental self-efficacy, or supportive learning environments including teacher encouragement, school culture, and access to sustainability-oriented learning facilities may be potential mediators. This interpretation aligns with Liu et al. (2023), who emphasized that personal motivation and contextual learning support are pivotal in transforming knowledge into real-world sustainable practices. Therefore, while cognitive enhancement remains essential, these findings suggest it is insufficient. Psychological (e.g., affect and motivation) and structural (e.g., pedagogical and institutional) supports must be intentionally cultivated to ensure that sustainability knowledge is effectively internalized and translated into consistent behavioral outcomes.

The findings of this study are consistent with those reported by Mangunjaya et al. (2013), who found that although students acquired environmental knowledge through formal education, such knowledge did not necessarily translate into sustainable attitudes or behaviours. Their study revealed that only 52% of students engaged in activities reflecting sustainability, and 62% demonstrated limited environmental awareness. This highlights a significant gap between the cognitive, socio-emotional, and behavioral domains, which remains a persistent challenge in sustainability education.

Similarly, Hidayah et al. (2020) reported that while most students exhibited a high level of knowledge regarding waste management, actual practices remained low. Their data showed that many students had yet to implement proper waste separation. This reinforces the notion that knowledge alone does not guarantee behavioral change, particularly when it is not supported by habitual practice, internalised values, or institutional systems that facilitate consistent behavioral transformation.

Furthermore, Latifah et al. (2023) emphasised that sustainability-oriented instruction on substances and their changes can effectively cultivate students' cognitive, socio-emotional, and behavioral competencies. Nevertheless, interviews with teachers revealed challenges in implementing differentiated instruction due to difficulties in developing teaching modules and student worksheets. This suggests that the successful cultivation of sustainability-related actions depends not only on students' disposition but also on the readiness and capacity of educators to employ contextually relevant and pedagogically sound approaches.

Overall, the present study underscores the importance of pedagogical approaches beyond cognitive transmission, fostering emotional engagement and providing authentic, hands-on experiences in sustainable practices. Integrating conceptual knowledge with project-based learning and value-based reflection is essential for nurturing comprehensive sustainability competencies in students.

Results of Semi-structured Interviews

The following are the results of semi-structured interviews with science teachers and several randomly selected students:

Science Teacher

The teacher stated, "The topic of changes in matter is taught according to the textbook and curriculum, but there has been no explicit connection to the SDGs because it is not mentioned in the textbooks." The teacher admitted that they have never attended training or workshops related to ESD. They also mentioned time constraints as a

significant challenge: "It is often not enough time to cover the core learning objectives, let alone add sustainability content." The teacher acknowledged the importance of linking science lessons with the SDGs but felt that school support in training and teaching modules would be necessary. "If there were thematic modules connecting culinary practices with science concepts and sustainability, I think it would benefit us teachers."

Students

The majority of students are unfamiliar with the terms SDG or ESD. One student stated, "I only heard the word SDG from my teacher during this interview." In cooking practice, students admitted to focusing on taste, cleanliness, and basic techniques. One student explained, "We are taught how to make delicious and hygienic food, but we have never discussed food waste or energy." When asked about sustainability attitudes, some students admitted to routinely throwing food scraps into the trash without sorting. Only one out of five students mentioned ever making compost from vegetable scraps at home, and that was due to an assignment in junior high school. Most students expressed interest if science lessons were linked to sustainable cooking practices. One student was intrigued by science lessons related to SDG 12 and Culinary, saying, "If the science material included cooking practices and ways to reduce fruit or vegetable peel waste, it sounds fun and would help me understand better."

Thematic mapping of qualitative data from teacher, analyzed using NVivo 12, is presented in Figure 3. Three key themes were identified: (1) barriers to ESD implementation, including limited instructional time and the pressure to prioritize completion of core content; (2) curriculum constraints and the absence of explicit SDG integration in textbooks; and (3) teacher readiness, characterized by a lack of exposure to ESD training and the expressed need for thematic modules that connect science content, culinary practice, and SDG 12 in a practical and contextualized manner.

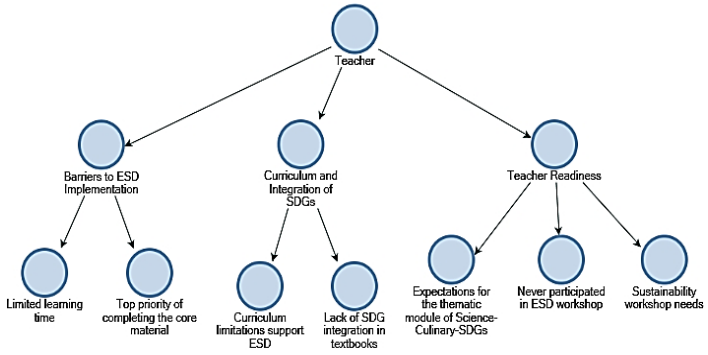

Figure 3. Thematic mapping of teacher responses from qualitative analysis

Thematic mapping of student responses from qualitative analysis is presented in Figure 4. Three main themes emerged: (1) limited literacy on SDGs or ESD, as these topics have not been explicitly introduced in class; (2) unsystematic sustainability practices, such as waste disposal without sorting and limited prior experience with composting; and (3) the perceived potential of integrating science learning with culinary practices, which sparked student interest and was viewed as more meaningful and engaging.

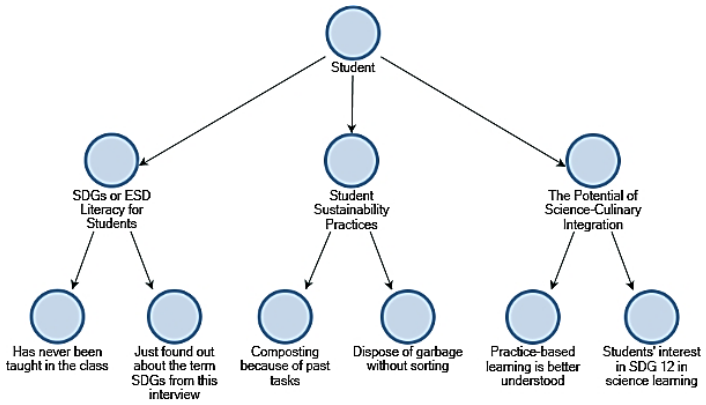

Figure 4. Thematic mapping of student responses from qualitative analysis

The interview results emphasise a gap between conceptual knowledge and real sustainability actions, both from the teachers' and students' perspectives. This reinforces the need for science education interventions that integrate ESD principles contextually in culinary practices.

Literature Mapping on ESD in Vocational Education

The findings regarding the low socio-emotional and behavioural domains of culinary vocational students indicate a tangible gap between conceptual understanding and awareness and real actions in sustainability practices. Although students possess sufficient knowledge about environmental issues and sustainability, this awareness has not yet been internalized into attitudes and behaviours.

The literature mapping results using VOSviewer in Figure 5 reinforce this interpretation. A co-occurrence analysis of articles from the last five years reveals that global research on ESD in vocational education tends to focus on structural issues such as curriculum (red cluster), teacher roles (blue cluster), and institutional policies (green cluster). Meanwhile, the applicative dimension such as empowering student action through direct learning experiences remains underexplored. The yellow cluster, which includes terms such as environment, science, and awareness, indicates the importance of a science- and environment-based approach. However, it does not sufficiently emphasize integrating real-world practices in vocational contexts.

The findings of this study provide a valuable foundation for designing more contextual and application-oriented instructional interventions. We recommend the development of a project-based learning module that engages students in hands-on activities to create food or beverage products using fruit or vegetable peels, while integrating sustainability concepts and principles of physical and chemical changes during the cooking process. This strategy aims to foster emotional engagement and bridge the gap between conceptual understanding and real-world application.

Nevertheless, this study has several limitations, particularly the small sample size and the focus on a single vocational school. These constraints limit the generalizability of the findings, as the observed trends may not accurately represent the broader

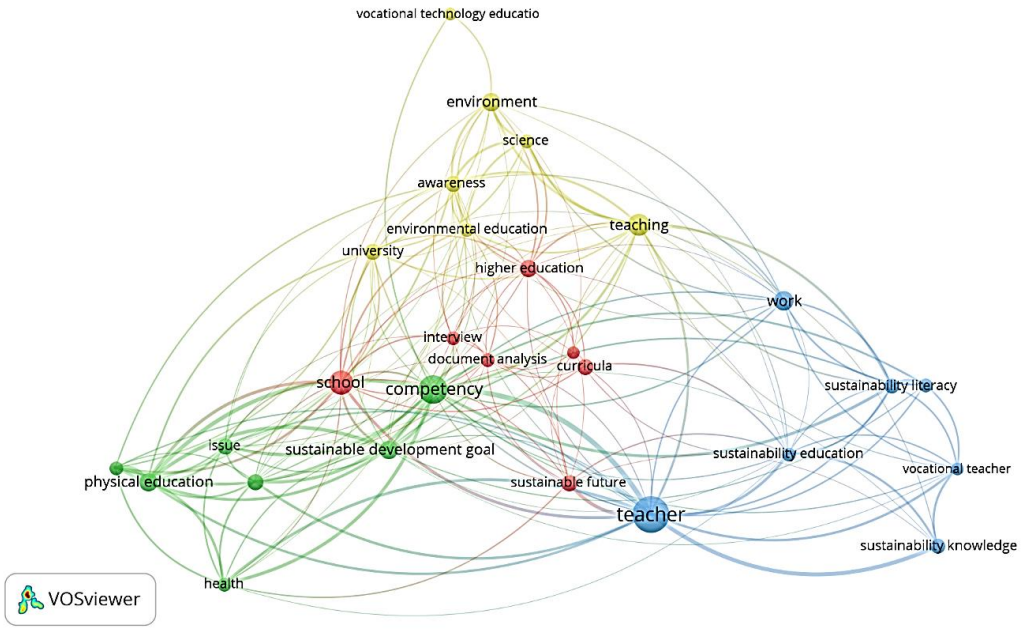

Figure 5. Keyword co-occurrence map of research on education for sustainable development in vocational education (VOSviewer output)

population of vocational students across different disciplines or geographical regions. Therefore, future research should include diverse samples from various vocational institutions and regions. Broader methodological approaches, such as longitudinal studies or quasi-experimental designs, may also provide a more comprehensive understanding of the impact of ESD interventions on students' sustainability competencies over time.

In addition, further exploration of potential mediating and moderating variables is necessary better to explain the relationship between sustainability knowledge and sustainable actions. Factors such as student motivation, institutional support, teacher competence in implementing ESD, and prior experience with sustainability practices significantly influence the successful internalisation of sustainability values.

▪ CONCLUSION

This study reveals that while students possess adequate sustainability knowledge, their socio-emotional and behavioral domains remain low. Therefore, ESD interventions in science education that are contextually relevant to culinary vocational programs are highly needed. The practical implication of these findings is the need to develop science learning materials that integrate SDG 12 principles with culinary laboratory activities and teacher training programs to design ESD intervensions. Future research may evaluate the effectiveness of the developed intervention through a quasi-experimental approach across various schools and vocational disciplines.

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