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# STEM Laboratory Competencies and Sustainable Development Goals: A Senior High School Curriculum Mapping Study in Biology, Chemistry, and Physics

**[1]Loren Mae Chavez, [2]Joshua Soldivillo, [3]Brenda R. Boladola**
Silliman University Senior High School
[1]lorenchavez@su.edu.ph, [2]joshuassoldivillo@su.edu.ph, [3]brendarboladola@su.edu.ph

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Corresponding Email:
lorenchavez@su.edu.ph

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**Index Terms:**

curriculum mapping, Delphi study, STEM laboratory competencies, Sustainable Development Goals (SDGs), sustainability education

**Abstract.** The integration of sustainability principles into STEM laboratory education remains insufficiently examined, particularly in relation to how curricular competencies align with global sustainability frameworks. This study addresses this gap by analyzing the alignment of Senior High School STEM laboratory competencies in Biology, Chemistry, and Physics with selected Sustainable Development Goals (SDGs), specifically SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land). A sequential two-phase design was employed. First, a Delphi method was used to identify and validate laboratory competencies based on expert consensus. Second, the validated competencies were mapped to the selected SDGs using a qualitative curriculum mapping approach, supported by frequency and percentage analyses. The findings revealed that a distinct set of competencies across the three disciplines can be meaningfully classified as laboratory competencies, emphasizing experimentation, measurement, and scientific inquiry. Alignment analysis showed that Chemistry competencies demonstrated the most balanced alignment across the SDGs, particularly in relation to water quality and climate processes, while Biology competencies aligned strongly with terrestrial ecosystems (SDG 15). Physics competencies exhibited moderate alignment, primarily through applications in environmental monitoring and climate-related analysis. However, alignment across all disciplines was found to be largely implicit, with notable gaps in competencies explicitly addressing water systems and marine environments. The study concludes that while existing STEM laboratory competencies provide a strong foundation for sustainability education, more explicit integration of SDG-related contexts is needed. The findings offer practical insights for curriculum development and highlight the potential of laboratory instruction in advancing education for sustainable development.

## Introduction

The increasing complexity of global challenges such as climate change, resource depletion, biodiversity loss, and social inequities underscores the urgent need for integrated and sustainable solutions. These challenges are inherently interconnected, as emphasized in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Nexus Report, which highlights that biodiversity, water, food, health, and climate systems are deeply interdependent (IPBES, 2025). The physical science basis of climate change, including its causes and projected impacts, has been comprehensively documented, further reinforcing the urgency of integrated responses (IPCC, 2021). In response, the United Nations established the Sustainable Development Goals (SDGs), a comprehensive framework of 17 goals designed to address these pressing global issues by 2030 (United Nations, 2015). Achieving these goals requires not only policy and technological innovation but also the development of competencies through education that enable individuals to respond effectively to sustainability challenges.

STEM (Science, Technology, Engineering, and Mathematics) education plays a critical role in cultivating the knowledge and skills necessary to address sustainability-related issues. Within STEM education, laboratory-based learning is particularly significant, as it promotes inquiry, experimentation, and the application of scientific concepts in authentic contexts. The laboratory has long been recognized as a central component of science education, with evidence suggesting that participation in laboratory activities can significantly enhance student learning and engagement (Hofstein & Lunetta, 2004). Empirical findings further indicate that laboratory-based instruction contributes to the development of essential 21st-century skills, including problem-solving (82%), critical thinking (78%), creativity (75%), communication (68%), and collaboration (63%) (Zulfa & Malik, 2025). These competencies are not only foundational to scientific literacy but are also directly relevant to addressing real-world sustainability challenges.

Recent pedagogical approaches, such as inquiry-based learning and project-based learning, have been identified as effective strategies for integrating sustainability into STEM education. These approaches bridge the gap between theoretical knowledge and real-world application by engaging students in hands-on, collaborative problem-solving tasks (Chang et al., 2024; Wiek et al., 2014). In particular, sustainability-oriented laboratory experiences—such as those involving climate resilience, renewable energy, and environmental monitoring—enable learners to connect disciplinary knowledge to global challenges while enhancing engagement and scientific literacy (Poya, 2026). Systematic reviews further affirm that inquiry-based and problem-based approaches are among the most effective means of embedding sustainability concepts within STEM education (Álvarez Ariza & Olatunde-Aiyedun, 2024), while case-based implementations demonstrate explicit alignment with SDGs related to climate action, water quality, and sustainable ecosystems (Gattinoni et al., 2025).

Despite these advances, the explicit alignment between STEM laboratory competencies and the Sustainable Development Goals remains underexplored, particularly within the context of Senior High School education. While existing literature supports the potential of laboratory instruction to contribute to sustainability education, there is limited empirical evidence examining how specific curricular competencies correspond to SDG targets. This gap is especially critical in domains such as clean water and sanitation (SDG 6), climate action (SDG 13), life below water (SDG 14), and life on land (SDG 15), where scientific knowledge and laboratory skills are essential for developing sustainable solutions (United Nations, 2015, Goals 6, 13, 14, and 15).

In the Philippine context, the Most Essential Learning Competencies (MELCs) serve as key guides for instructional delivery within the K to 12 curriculum, particularly in Senior High School STEM specialized subjects such as Biology, Chemistry, and Physics (Department of Education, 2016; Educators' Files, 2019). However, the identification of which competencies should be prioritized for laboratory instruction, as well as the extent to which these laboratory competencies align with sustainability objectives, has not been systematically examined. Establishing expert-validated laboratory competencies and determining their alignment with the SDGs are essential steps toward ensuring that STEM education meaningfully contributes to sustainability-oriented learning.

To address this gap, the present study adopts a two-phase approach by first identifying and validating laboratory competencies in Senior High School Biology, Chemistry, and Physics through expert consensus, and subsequently examining how these competencies correspond to selected Sustainable Development Goals. Specifically, the study seeks to determine (1) which STEM competencies in Senior High School Biology, Chemistry, and Physics are identified and validated as laboratory competencies through expert consensus, and (2) the extent to which these identified laboratory competencies align with SDGs 6 (Clean Water and Sanitation), 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land).

This study contributes to the growing body of literature on STEM education for sustainable development by providing an empirically grounded mapping of laboratory competencies to global sustainability goals. The findings offer practical insights for curriculum developers, educators, and policymakers in strengthening the integration of sustainability principles into laboratory instruction. Ultimately, the study supports the development of more responsive and future-oriented STEM curricula that equip learners to address complex environmental challenges.

## Methodology

*Research Design*

This study employed a sequential two-phase research design to examine the alignment of STEM laboratory competencies with selected Sustainable Development Goals (SDGs). The design integrates a consensus-based approach and qualitative curriculum mapping to ensure both the validity of identified laboratory competencies and the rigor of their alignment with sustainability frameworks.

The first phase utilized the Delphi method to establish expert consensus on which competencies in Senior High School Biology, Chemistry, and Physics should be prioritized as laboratory competencies. The Delphi approach is particularly appropriate for studies requiring systematic judgment from experts in areas where predefined criteria are limited, as it enables the refinement and validation of concepts through iterative evaluation. The second phase employed a curriculum mapping approach to analyze the extent to which the validated laboratory competencies align with selected SDGs, specifically SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land). This approach allows for a structured examination of how curricular elements correspond to broader sustainability goals and facilitates the identification of alignment patterns and gaps.

This design provides a coherent framework for linking expert-validated laboratory competencies with global sustainability objectives, thereby strengthening the analytical depth and validity of the study.

*Participants and Sampling Technique*

The Delphi study involved a panel of thirty (30) expert teachers purposively selected based on established criteria of professional expertise. Participants were required to have at least five (5) years of teaching experience within the Department of Education and/or hold a Master Teacher position at the senior high school level. These criteria were used to ensure that participants possessed sufficient pedagogical experience and subject-matter expertise relevant to the study.
Purposive sampling was employed to identify and recruit participants who met the defined qualifications. The use of expert selection is consistent with Delphi methodology, which prioritizes informed judgment over representativeness in order to achieve reliable consensus among knowledgeable individuals.

*Data Gathering Procedure*

Data gathering was conducted in three sequential phases: (1) document analysis of curriculum guides, (2) expert validation of identified competencies, and (3) mapping of validated competencies to selected Sustainable Development Goals (SDGs). In the first phase, curriculum document analysis was performed using the official Department of Education (DepEd) Senior High School STEM curriculum guides for Physics, Chemistry, and Biology. Laboratory-related competencies were extracted, focusing on skills such as designing experiments, analyzing data, and applying scientific concepts. The extracted competencies were then organized and categorized into thematic groupings, including scientific inquiry, technological literacy, environmental science, and problem-solving.

In the second phase, the categorized competencies were subjected to expert validation. Subject-matter experts (SMEs) reviewed the extracted competencies to assess their clarity, relevance, and alignment with laboratory-based instruction. Based on the feedback provided, the researchers refined the competency list by revising, consolidating, or removing items that were redundant, unclear, or outdated.

In the third phase, the validated competencies were systematically mapped to selected Sustainable Development Goals, specifically SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land). Each competency was examined in relation to the goals and their corresponding targets to determine alignment. The mapping process was conducted collaboratively by the researchers and subsequently reviewed by the SMEs to ensure conceptual consistency and relevance to sustainability objectives.

*Data Analysis Procedure*

Data analysis was conducted using a combination of consensus-based and qualitative approaches to ensure a systematic examination of both the identification of laboratory competencies and their alignment with selected Sustainable Development Goals (SDGs). Initially, responses from subject-matter experts (SMEs) were analyzed to establish consensus on which competencies should be classified as laboratory competencies. Descriptive statistics were employed to summarize expert ratings, and predetermined criteria for consensus—based on measures of central tendency and level of agreement—were applied to determine the inclusion, revision, or exclusion of competencies. Competencies that met the established threshold were retained as validated laboratory competencies, while those that did not were either refined based on expert feedback or excluded. In addition, qualitative comments provided by the experts were examined to support the clarification and improvement of competency statements.

Following the establishment of validated laboratory competencies, the analysis proceeded with the examination of their alignment with selected SDGs, specifically SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land). A qualitative curriculum mapping approach was employed to determine how each competency corresponds to relevant SDG targets and themes. This involved identifying both explicit and implicit connections between competencies and sustainability objectives, and subsequently organizing competencies according to their associated SDGs.

To further characterize the extent of alignment, frequency counts and percentage distributions were computed to determine the proportion of competencies linked to each SDG. These quantitative summaries complemented the qualitative mapping by highlighting patterns of alignment as well as areas of underrepresentation across Biology, Chemistry, and Physics. Through this integrated analytical process, the study was able to provide a coherent assessment of how expert-validated laboratory competencies contribute to sustainability-oriented education.

*Ethical Considerations*

This study adhered to established ethical standards in the conduct of research involving human participants. Participation of subject-matter experts (SMEs) in the Delphi process was entirely voluntary, and informed consent was obtained prior to their involvement. Participants were provided with clear information regarding the purpose of the study, the nature of their participation, and their right to withdraw at any stage without penalty.

To ensure confidentiality, the identities of the participating experts were not disclosed in any part of the study. Responses were anonymized during data processing and analysis, and all data were reported in aggregate form to prevent the identification of individual participants.

Furthermore, the study involved the analysis of publicly available curriculum documents, which did not require additional ethical clearance. All collected data were used solely for research purposes and were handled in accordance with applicable data privacy and research ethics guidelines.

## Results and Discussion

*Identification and Validation of Laboratory Competencies*

The first phase of the study focused on identifying and validating laboratory competencies in Senior High School Biology, Chemistry, and Physics through expert consensus. Using the Delphi method, subject-matter experts (SMEs) evaluated competencies extracted from the curriculum and determined which should be prioritized for laboratory instruction.

The results indicate that a subset of competencies across the three disciplines was consistently identified as laboratory-relevant, reflecting their emphasis on experimentation, measurement, data analysis, and application of scientific principles. In Physics, validated competencies are largely centered on quantitative analysis and instrumentation, including measuring electrical quantities, analyzing motion, and applying physical laws. In Chemistry, competencies emphasized experimental processes such as separation techniques, solution preparation, reaction analysis, and electrochemical applications. In Biology, the identified laboratory competencies were primarily associated with cellular processes, organismal functions, and genetic and ecological concepts that lend themselves to investigation and observation.

The consensus among experts highlights a shared recognition that laboratory competencies are not merely content-based but are defined by their potential to engage students in hands-on inquiry and scientific investigation. This aligns with existing literature emphasizing the role of laboratory experiences in developing higher-order thinking and practical scientific skills (Hofstein & Lunetta, 2004). Moreover, the validated competencies reflect a balance between conceptual understanding and procedural skills, suggesting that effective laboratory instruction in STEM requires both theoretical grounding and experiential learning. A curricular Delphi study in Spain by Charro (2020) similarly demonstrated that expert consensus can robustly identify desirable competencies, with findings underscoring that "science education related to environmental issues and human health" is a critical outcome of effective secondary science training.

These findings establish a validated set of laboratory competencies that serve as the basis for subsequent alignment with sustainability goals (see Appendix A). Importantly, the use of expert consensus strengthens the credibility of the identified competencies, ensuring that the mapping process is grounded in disciplinary and pedagogical expertise.

*Alignment of Laboratory Competencies with Sustainable Development Goals*

Following the validation of laboratory competencies, the second phase examined their alignment with selected Sustainable Development Goals (SDGs 6, 13, 14, and 15). The results reveal varying degrees of alignment across disciplines, reflecting both the strengths and limitations of current STEM laboratory curricula in addressing sustainability objectives.

*Physics*

Physics laboratory competencies demonstrated moderate alignment with SDGs, particularly in areas related to environmental monitoring and climate analysis. The highest alignment was observed with SDG 14 (Life Below Water, 44%), where competencies such as projectile motion, measurement of electrical quantities, and motion analysis were linked to applications in marine research and environmental monitoring.

Alignment with SDG 13 (Climate Action, 33%) and SDG 15 (Life on Land, 33%) was also evident, particularly through competencies involving thermal expansion, motion analysis, and the application of physical laws in environmental contexts. However, alignment with SDG 6 (Clean Water and Sanitation, 11%) was limited, with only one competency directly associated with water quality monitoring. Recent research investigating teacher readiness for SDG-integrated STEM education found that 100% of surveyed teachers were unfamiliar with the term "SDGs," and 90% rarely linked science concepts to socio-environmental contexts in their instruction (Purwaningsih et al., 2025). It is possible that proper alignment may contribute to familiarity and better integration in the classroom.

These findings suggest that while Physics competencies can be applied to sustainability contexts, their alignment is often indirect and requires contextualization. This reflects the abstract nature of many Physics concepts, which may not explicitly reference environmental applications unless deliberately integrated into instruction.

*Chemistry*

Chemistry laboratory competencies exhibited the most balanced and substantial alignment across the selected SDGs. The highest alignment was observed with SDG 6 (Clean Water and Sanitation, 35%), reflecting the strong relevance of chemical principles in water purification, solution chemistry, and analytical techniques.

Moderate alignment was also observed with SDG 13 (Climate Action, 30%) and SDG 14 (Life Below Water, 30%), with competencies related to gas laws, reaction rates, and acid-base chemistry supporting understanding of atmospheric processes and marine ecosystems. Alignment with SDG 15 (Life on Land, 25%) was evident through competencies related to soil chemistry, reaction energetics, and environmental processes.

This strong applicability of chemistry to environmental issues is mirrored in international higher education frameworks. For instance, university-level chemistry-related courses integrate Sustainable Development Goals such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) into their teaching plans, linking scientific concepts to sustainability-oriented practices (Teaching Guides Query, 2023).

The relatively higher and more distributed alignment of Chemistry competencies highlights the discipline's direct applicability to environmental and sustainability issues. Chemical processes are inherently linked to real-world systems, making Chemistry a critical domain for integrating sustainability into laboratory instruction.

*Biology*

Biology laboratory competencies showed the strongest alignment with SDG 15 (Life on Land, 36%), emphasizing the discipline's focus on biodiversity, ecosystem processes, and organismal interactions. Competencies related to classification, genetic processes, and ecological understanding directly support terrestrial sustainability and conservation efforts.

Alignment with SDG 13 (Climate Action, 27%) was also observed, particularly through competencies related to cellular respiration, biological molecules, and genetic adaptation, which are relevant to carbon cycling and climate resilience. However, alignment with SDG 6 (18%) and SDG 14 (18%) was comparatively limited, indicating fewer explicit connections to water systems and marine environments.

Community-based biology training programs, for example, have linked plant cultivation and propagation practices to sustainability goals such as Life on Land (SDG 15) and Responsible Consumption and Production (SDG 12), demonstrating the practical application of biological knowledge in conservation and sustainable resource management (Universitas Gadjah Mada Faculty of Biology, 2024).

These results suggest that while Biology provides strong foundations for understanding ecosystems, its laboratory competencies may require further expansion to explicitly address aquatic and water-related sustainability issues.

*Cross-Disciplinary Patterns and Implications*

Across the three disciplines, several patterns emerge. First, alignment with the selected SDGs is uneven, with certain goals—particularly SDG 14 and SDG 15—receiving stronger representation depending on the discipline. Chemistry demonstrates the most balanced alignment, while Physics and Biology exhibit more domain-specific contributions. Second, the findings reveal that many competencies support sustainability objectives only implicitly. This suggests that while the foundational knowledge exists within the curriculum, explicit integration of sustainability contexts is necessary to fully realize its potential. This need for explicit integration is a central theme in contemporary educational reform. European green education initiatives promote a multidisciplinary STEM approach in which environmental issues such as climate change and sustainability are integrated into learning, enabling students to apply concepts from physics, chemistry, and biology to real-world challenges (Erasmus+ Project, 2023). This best practice may be adopted and adapted by the Philippines. Third, the results highlight opportunities for curriculum enhancement. Increasing the representation of competencies related to water systems (SDG 6) and marine ecosystems (SDG 14), as well as promoting interdisciplinary integration across Physics, Chemistry, and Biology, may strengthen the overall alignment of STEM education with sustainability goals.

The alignment analysis underscores the potential of STEM laboratory competencies to contribute to sustainability education, while also identifying critical areas for improvement in curriculum design and implementation.

## Conclusion and Recommendations

This study examined the alignment of Senior High School STEM laboratory competencies in Biology, Chemistry, and Physics with selected Sustainable Development Goals (SDGs 6, 13, 14, and 15) through a two-phase approach involving expert validation and curriculum mapping. Addressing the first research question, the findings confirmed that a distinct set of competencies across the three disciplines can be meaningfully classified as laboratory competencies based on expert consensus. These competencies emphasize experimentation, measurement, data analysis, and the application of scientific principles, reinforcing the central role of laboratory instruction in developing both conceptual understanding and practical scientific skills.

In response to the second research question, the results revealed that the identified laboratory competencies demonstrate varying levels of alignment with the selected SDGs. Chemistry exhibited the most balanced alignment across all four goals, particularly in relation to clean water and climate action, reflecting the direct applicability of chemical principles to environmental systems. Biology showed strong alignment with life on land, highlighting its focus on biodiversity and ecosystem processes, while Physics demonstrated moderate alignment, primarily through applications in environmental monitoring and climate-related analysis. However, the overall distribution of competencies indicates that alignment is often implicit rather than explicit, with certain areas—particularly water systems and marine ecosystems—remaining underrepresented.

These findings suggest that while the current STEM curriculum provides a strong foundation for sustainability education, there is a need for more intentional and explicit integration of SDG-related contexts within laboratory instruction. The identification of validated laboratory competencies offers a valuable basis for curriculum refinement, ensuring that laboratory activities are not only scientifically rigorous but also socially and environmentally relevant.

From a practical standpoint, the study provides several implications. For curriculum developers, the results highlight the importance of embedding sustainability-oriented competencies across disciplines, particularly in areas with limited representation, such as SDG 6 and SDG 14. For educators, the findings underscore the need to contextualize laboratory activities within real-world sustainability challenges, thereby making implicit connections more explicit in classroom practice. For policymakers, the study offers empirical support for strengthening the alignment between national curricula and global sustainability frameworks, contributing to the broader goal of education for sustainable development.

These said, this study demonstrates that STEM laboratory competencies have significant potential to support the achievement of the Sustainable Development Goals. By refining and contextualizing these competencies, educational systems can better equip learners with the knowledge and skills necessary to address complex environmental challenges and contribute meaningfully to a sustainable future.

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## Competing Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

## Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to confidentiality considerations involving expert participants but are available from the corresponding author upon reasonable request. Publicly available curriculum documents used in this study can be accessed through the Department of Education (DepEd) K to 12 Curriculum Guides.

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## Appendices

No appendices are attached to this study.