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THE UTILIZATION OF ORGANIC WASTE IN BIOTECHNOLOGY LEARNING THROUGH PjBL/STEM TO ENHANCE SCIENTIFIC SKILLS AND CREATIVITY: A SYSTEMATIC EVIDENCE SYNTHESIS

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ABSTRACT

The accumulation of household and agricultural organic waste poses serious ecological problems, but also opens up opportunities for utilization in contextual and sustainability-oriented biotechnology learning. This study aims to systematically analyze the international literature on the integration of the use of organic waste in biotechnology learning to improve students' scientific skills and creativity, especially through the Project-Based Learning model and STEM approach. The method used is *a Systematic Literature Review* guided by PRISMA with the main source of the Scopus database (2017–2025), followed by qualitative analysis using NVivo to identify research themes, trends, and gaps. The results show that various forms of organic waste utilization such as eco-enzyme production, compost, and enzyme extraction from biomass, within the framework of PjBL/STEM consistently contribute to improving science literacy, scientific process skills, creative thinking skills, and ecological awareness, although there are still limitations of standardized instruments and variations in the quality of study design. It is concluded that the integration of organic waste in biotechnology learning, supported by the PjBL/STEM framework, digital technology, and local wisdom, is a promising instructional strategy for the development of innovative and responsive science curricula to 21st century competencies.
Keywords: utilization of organic waste; biotechnology; PjBL

INTRODUCTION

The ever-increasing accumulation of organic waste, dominated by household and agricultural sources, has become an urgent global environmental concern due to its significant contribution to pollution and greenhouse gas emissions (Vidalia *et al*., 2023). In the context of sustainable development, effective waste-conversion strategies such as producing liquid organic fertilizers, eco-enzymes, or biomass energy are required to minimize ecological impacts (Alao *et al.*, 2024; Sulistiana, 2025). Education plays a crucial role in responding to these challenges, as integrating sustainability issues into the secondary-school science curriculum is essential to develop environmentally aware learners with strong problem-solving capacities (Nurhayati & Abidin, 2025). Specifically, wet organic waste–based eco-enzyme production has been recognized as a technically and economically feasible solution that supports Sustainable Development Goals (SDGs) (Sesrita *et al.*, 2025). Therefore, embedding organic-waste contexts into science learning is not only ecologically relevant but also pedagogically meaningful, particularly when viewed through constructivist theory and contextual learning perspectives, which emphasize the importance of connecting scientific concepts to authentic, real-life problems to enhance scientific reasoning and creativity.

From a theoretical perspective, waste-based biotechnology learning provides authentic experiences aligned with constructivist and contextual learning principles, in which students actively build scientific understanding through observation, experimentation, and interpretation of real materials such as vegetable waste, fruit peels, and biomass. This aligns with empirical findings showing that using organic waste such as eco-enzyme materials or residual biomass supports students' scientific literacy development and strengthens their ability to connect concepts with environmental contexts (Astuti *et al.*, 2025). In addition, integrating meaningful, real-world problems in science learning has been associated with increased intrinsic motivation and creativity, particularly when students are involved in open-ended biotechnology tasks that allow them to design procedures, make decisions, and evaluate environmental impacts (Fentiana *et al*., 2025).

Recent developments in science education demand a substantial shift from traditional memorization-based instruction to the cultivation of 21st-century competencies through active, contextualized, and technology-enhanced learning models. Project-based learning (Project-Based Learning/PjBL), when integrated with digital tools such as Live Worksheets, has been shown to promote creative thinking and ecopreneurship among students in biotechnology topics (Avinni Achmad *et al.*, 2024). Similarly, the Science, Technology, Engineering, and Mathematics (STEM) approach enriched with socio-scientific issues (SSI) has demonstrated positive effects on students' creativity in addressing authentic environmental challenges (Live *et al*., 2025). The use of local contexts such as rubber seed processing or agricultural-waste utilization within PjBL-STEM modules is also acknowledged as important for strengthening creative problem-solving skills (Ursula *et al.*, 2024). This aligns with findings that web-based biotechnology modules can enhance eco-literacy among preservice science teachers (Wulandari *et al*., 2024).

Despite these advances, several educational and policy gaps remain evident in the implementation of sustainability-oriented biotechnology learning. Many schools still face limited access to laboratory equipment and contextual learning resources, which constrains teachers' ability to carry out practical waste-based projects aligned with PjBL/STEM frameworks (Nurhayati & Abidin, 2025). Additionally, although various studies have shown positive impacts of eco-enzyme projects, composting activities, and STEM-based waste processing on students' scientific and creative competencies, the integration of these approaches into national curricula remains inconsistent and often lacks systematic support from educational policy structures (Putri *et al*., 2025). These gaps highlight the need for stronger curricular alignment and infrastructure support to ensure that evidence-based sustainability practices can be broadly implemented in science classrooms.

Recent research trends (2020–2025) show an increasing interest in integrating local wisdom and conventional biotechnology in learning. Ethnoscience studies, such as traditional fermentation *Lemea* Bamboo shoots, have succeeded in bridging the community's original knowledge with the concept of modern biology in schools (Sri) *et al*., 2025). More

broadly, a systematic review of ethnoscience research in Indonesia confirms that this approach is effective in improving students' science literacy and environmental awareness (Wisdom) *et al.*, 2025). On the other hand, the use of specific wastes such as fruit peels for enzyme production is also the focus of intensive studies due to its wide application potential and educational value (Barman *et al.*, 2022). The integration of this local wisdom into environmental education not only preserves the culture but also provides a relevant and meaningful learning context for students (Sihombing *et al.*, 2025).

Although many studies report the success of waste-based learning interventions, there are variations in the focus and results of the research that need to be synthesized. For example, the application of the PjBL model in the manufacture of *eco-enzyme* Proven to train students' environmental care attitudes significantly (Putri *et al.*, 2025). Meanwhile, the use of differentiated electronic worksheets (e-LKPD) in organic waste treatment projects was positively perceived by teachers and students to improve critical thinking skills (Laughter) *et al.*, 2025). However, other studies highlight that while PjBL increases collaboration and creativity, challenges in implementation and consistency of results across demographic contexts are still found (Saputri & Maura, 2024). In addition, there is a gap in the literature regarding how the integration of biotechnology in PjBL-STEAM specifically affects critical and creative thinking skills simultaneously in various school settings (Salhuteru *et al.*, 2025)Ps.

This study aims to systematically analyze and synthesize the latest literature on the integration of the use of organic waste in biotechnology learning in order to evaluate the effectiveness of pedagogical approaches, especially *Project-Based Learning* and STEM models, on improving students' scientific skills and creativity. This study is focused on mapping dominant research trends, identifying methodological and contextual gaps in previous studies, and formulating a comprehensive conceptual framework as a foundation for the development of innovative science instructional strategies and curricula, relevant to environmental sustainability issues, and responsive to the needs of 21st century competencies.

METHODS

Research Design

This study adopts a systematic literature review (SLR) approach to map and evaluate the current status and global trends related to the use of organic waste in the context of biotechnology learning. The primary focus is to understand how various pedagogical approaches contribute to the improvement of students' scientific skills and creativity. The SLR approach was chosen because it enables the identification, selection, and assessment of literature in a structured, transparent, and replicable manner, leading to the development of a comprehensive and objective scientific synthesis. In addition, this study incorporates specific procedures to manage methodological heterogeneity across the included studies, such as differentiating experimental, quasi-experimental, and descriptive designs; assessing the suitability of quantitative outcomes for potential comparative synthesis; and determining when studies should be integrated only through qualitative thematic analysis due to incompatible metrics or insufficient statistical reporting.

The methodological framework of this study is designed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline, which is widely used in systematic review research in education and science. The implementation of PRISMA ensures that all stages from formulating research questions, constructing search strategies, selecting studies, extracting data, evaluating methodological quality, to synthesizing and reporting findings are conducted with high precision and accountability. To further address variability across studies, the screening process also includes an assessment of operational definitions, outcome measures, and intervention characteristics to ensure comparability and to determine the appropriate synthesis pathway for each study category.

In addition to the systematic review procedure, this research also employs in-depth qualitative analysis using NVivo software. NVivo is used to systematically identify and categorize key themes, central concepts, and developmental patterns emerging from the selected literature. Through coding, classification, and clustering, the software enables researchers to map conceptual relationships across studies, particularly regarding organic waste utilization methods, biotechnology learning implementation, and indicators related to students' scientific skills and creativity. This combined approach systematic review following PRISMA and qualitative thematic analysis using NVivo provides a comprehensive and structured understanding of current research developments and methodological trends in the last decade.

Data Source

The main source of data for this systematic review was obtained from the Scopus database. Scopus was chosen because it is a credible and comprehensive scientific database, providing access to thousands of *peer-reviewed* literature from a wide range of disciplines. This credibility is essential to ensure the quality and relevance of the article to be analyzed. Scopus has a wide multidisciplinary scope, making it a perfect fit for this research topic that brings together the fields of organic waste utilization, biotechnology, education, scientific skills, and creativity. Additionally, its compatibility with bibliometric and qualitative analysis software, such as NVivo, makes it an ideal choice for data collection and analysis processes.

The data collection process is carried out directly through the Scopus web interface. This method allows researchers to perform efficient searches, apply various filters to filter results, and download article metadata in detail. The metadata to be collected includes the author's name, affiliation, year of publication, article title, journal name, number of citations, abstract, and keywords. This information is invaluable for initial analysis and document screening.

The documents sought will be limited to a specific year range, i.e. from 2017 to 2025. This restriction aims to focus on recent publications that reflect the latest developments in the use of organic waste in the context of biotechnology learning as well as its impact on the improvement of scientific skills and creativity. This time span also allows for the identification of the latest trends and innovations in methodologies and research findings in related fields.

The data that has been extracted from Scopus will be organized and analyzed using NVivo software. NVivo will be used to facilitate in-depth qualitative analysis of article content, including thematic coding, categorization, and identification of key patterns. It will help in synthesizing information from various studies, identifying research gaps, as well as formulating important findings related to the use of organic waste in biotechnology learning to improve students' scientific skills and creativity.

Search Strategy

The literature selection process in this study follows a transparent and replicable flow aligned with the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) guidelines. The stages of identification, screening, and inclusion are conducted systematically to ensure that all relevant literature is objectively identified and evaluated.

The initial search was conducted using the Scopus database, selected for its reputation as a multidisciplinary scientific index that provides access to a wide range of peer-reviewed publications. The Boolean queries applied in the search were as follows:

TITLE-ABS-KEY ("Organic Waste" OR "Organic Biomass" OR "Agricultural Waste" OR "Food Waste") AND TITLE-ABS-KEY ("Biotechnology Education" OR "Biotechnology Learning" OR "Biotechnology Instruction") AND TITLE-ABS-KEY ("Scientific Skills" OR "Science Process Skills" OR "Scientific Literacy") AND TITLE-ABS-KEY ("Creativity" OR "Creative Thinking" OR "Innovation") AND PUBYEAR > 2016 AND PUBYEAR < 2026

This search strategy was designed to gather documents relevant to the utilization of organic waste in biotechnology learning, especially those that explicitly examine outcomes related to scientific skills and creativity. To mitigate potential publication and language bias, additional procedures were implemented. First, a supplementary search of grey literature such as conference proceedings indexed in Scopus, institutional repositories, and open-access thesis or research reports was performed to capture studies that may not appear in major journals but remain methodologically relevant. Second, reference lists of all included articles were manually screened to identify additional eligible studies (“backward searching”). Third, when abstracts or metadata indicated relevant but inaccessible full texts, attempts were made to contact corresponding authors to retrieve the necessary materials. These steps were taken to ensure that the review remained comprehensive and reduced the risk of omitting important evidence due to publication venue, indexing limitations, or language restrictions.

In the next stage, language filters will be applied to include only English-language publications to maintain terminological consistency and minimize interpretation bias. In addition, document type screening will limit search results to research *articles* and *review articles*, excluding *short notes*, editorials, comments, *abstract-only papers*, and other publications that do not go through *the peer review* process strict. This screening process is important to ensure that the selected documents are of adequate scientific quality and directly address the integration of the use of organic waste in the context of biotechnology learning as well as its impact on students' scientific skills and creativity. A PRISMA diagram depicting

the stages of identification, *screening*, and *inclusion* will be presented to provide a comprehensive visualization of the process.

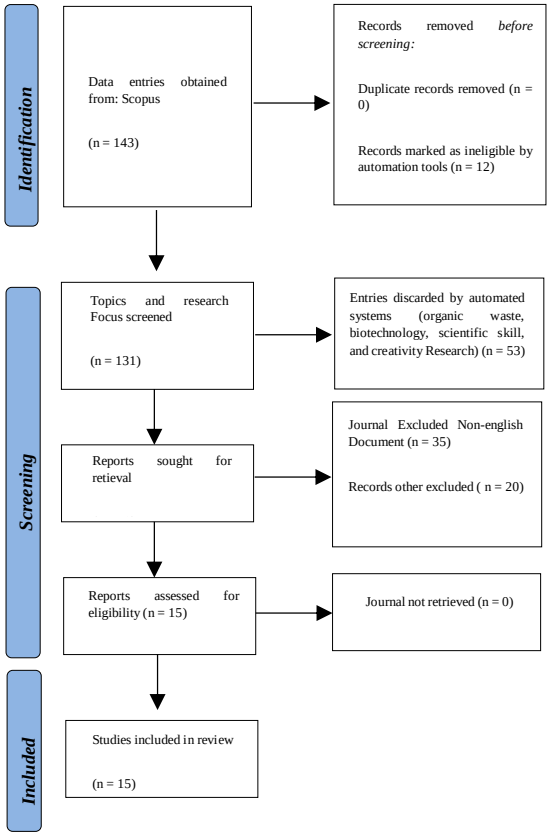


Figure 1. Article selection prism diagram

Analysis Parameters (Validity and Reliability)

This systematic review research will maintain its validity and reliability through a rigorous set of methodological measures. Validity will be ensured with full transparency in the entire process, from search to literature selection, following PRISMA guidelines. In addition, data analysis performed with NVivo software will help to carefully identify patterns and themes, ensuring that interpretations are based on strong evidence from the literature analyzed, thereby improving the internal validity of the findings.

The reliability of the research will be strengthened through the use of two independent reviewers in the selection and data extraction process. They will separately evaluate articles based on pre-established inclusion and exclusion criteria, with the potential for resolution of disagreements through discussion or the assistance of a third reviewer to minimize subjective bias. The use of agreement coefficients (e.g., Cohen's Kappa) will be used to measure consistency between reviewers.

Finally, reference management software such as Mendeley will be used to organize selected articles and record each selection decision systematically. This layered approach, including process transparency, tools-driven data analysis, independent reviewers, and meticulous documentation, collectively aims to maintain the scientific integrity of the research, ensure the consistency of review results, and enhance the credibility of the findings produced.

RESULTS AND DISCUSSION

1. Publication and Distribution Results of the Field of Study

The diagram in Figure 2 shows that of the 15 articles analyzed, the fields of STEM Education and Science Education each contributed 4 publications, representing approximately 26.7% of the total documents and indicating that both domains were the primary focus in research related to organic-waste-based biotechnology learning. Chemistry Education appeared in 2 articles (13.3%), while the remaining fields such as Engineering Education, Environmental Management, Technology & Engineering, Entrepreneurship Education, and Teacher Education were each represented by only 1 article (6.7%). Quantitatively, this distribution shows that more than half of the studies (8 of 15 articles, 53.4%) belonged to the science and STEM education cluster,

with the remaining publications (46.6%) spread across applied and supporting disciplines.

Beyond disciplinary distribution, these patterns also reflect practical considerations for implementing waste-based biotechnology learning in educational settings. Studies within STEM and science education tend to report the need for teacher training to handle biotechnological procedures, including the safe processing of vegetable or fruit waste and the facilitation of inquiry-based experimentation. Several studies also highlight that such interventions require relatively low-cost materials often using readily available household or agricultural waste making them feasible for schools with limited resources. However, even low-cost interventions still necessitate basic laboratory infrastructure, such as containers for fermentation, simple measurement tools, and safe waste-handling equipment, which some institutions may lack. Therefore, the concentration of publications in STEM and science education suggests not only academic interest but also the practical readiness of these fields to adopt and replicate waste-based biotechnology interventions in classroom settings.

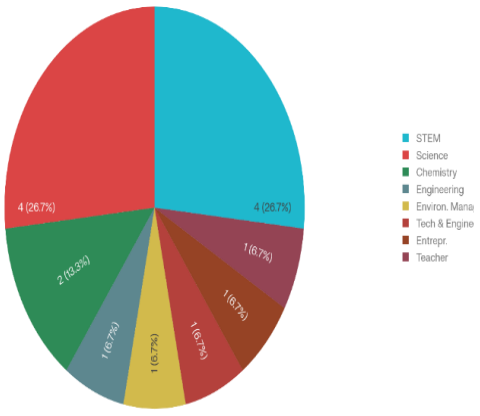


Figure 2. Documents by Subject Field

2. Author Productivity Analysis

Figure 3 shows the productivity of the first 15 authors, with Gita, R S D as the only author who produced 2 documents, while 14 other authors, such as Adhim, Fauzan; Astuti, A and D; Atmojo, Idam Ragil Widianto; Burch, R; Calvo, Sunday; to Djukri, each only contributed 1 document. This pattern quantitatively shows that 86.7% of the authors in figure 3 have a single productivity (1 article), while only 6.7% of the authors are slightly more dominant with 2 articles, so the publication landscape in this collection of documents tends to be very dispersed and collaborative, without a single author dominating strongly.

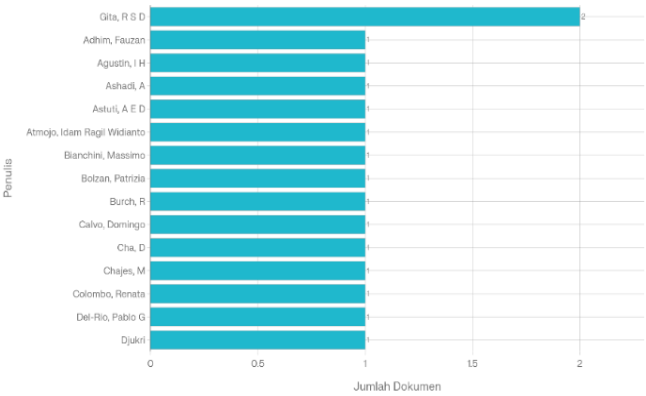


Figure 3. Documents by 15 Authors

3. Institutional and Affiliate Analysis

The document dataset also shows a specific pattern of academic concentration in terms of institutional affiliation, as illustrated in Figure 4. Northwestern University Feinberg School of Medicine leads with 5 documents, followed by Charité – Universitätsmedizin Berlin with 4 publications. Mid-tier institutions such as Northwestern University, Vrije Universiteit Amsterdam, and Amsterdam Public Health each contributed 3 documents, while other institutions from Humboldt-Universität zu Berlin to the University of Pittsburgh were represented by 2 publications. This

distribution indicates that research related to Item Response Theory and Computerized Adaptive Tests is grounded in reputable medical and public health institutions across the United States and Europe, demonstrating an intensive application of adaptive assessment technologies in clinical and psychometric measurement contexts.

Beyond institutional concentration, these findings also highlight important environmental and safety implications for implementing waste-based biotechnology learning. Although many interventions utilize low-risk materials such as fruit peels, vegetable scraps, or simple composting media, the handling of organic waste still requires attention to potential biological risks, including microbial growth, unpleasant odors, and contamination if the materials are not managed properly. Schools adopting such activities must therefore ensure basic safety protocols, such as using gloves, sealed containers, and appropriate waste storage practices. In addition, post-activity waste management must be addressed to avoid producing new environmental burdens, ensuring that residual materials are composted, disposed of safely, or repurposed according to local regulations. Integrating these environmental and safety considerations is essential for assessing the sustainability and replicability of organic-waste-based interventions, particularly when implemented in resource-limited educational settings.

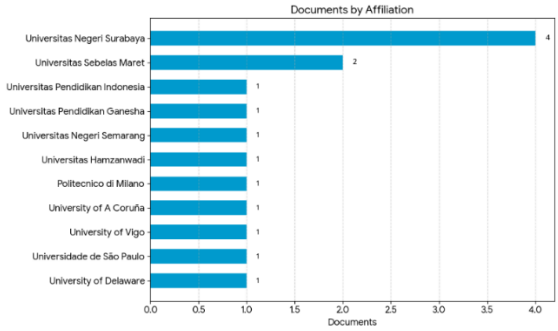


Figure 4. Documents based on Top 10 Publisher Parties

4. Geographical Distribution: Comparison of Author's Country of Origin and Country of Publication

Figure 5 shows a contrasting pattern of research dissemination, where the majority of intellectual contributions come from Indonesian authors (10 documents), but are channeled through publishers based in developed countries, especially the United States (7 documents) and the United Kingdom (3 documents). This gap between production and publication sites indicates a strong national academic orientation towards the internationalization of research, where local findings are published through global proceedings and journals (such as *AIP Conference Proceedings* and *IOP Publishing*) to reach a wider audience and meet international indexing standards, rather than being limited to domestic journals.

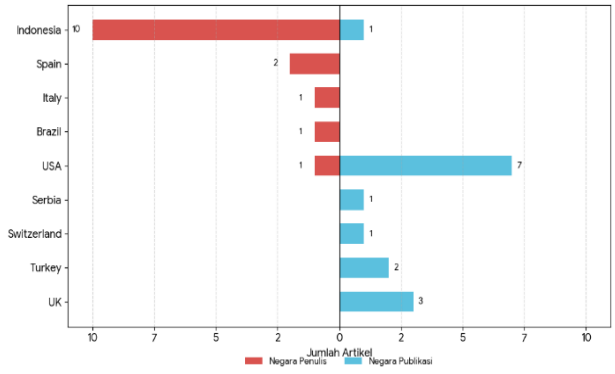


Figure 5. Comparison of Writing and Publication Countries

5. Data Visualization Results

The word cloud visualization in Figure 1, which was analyzed using the NVivo tool, highlights the words learning, waste, students, science, creativity, skills, and composting as the most dominant keywords, so that it is very much in line with the focus of the article collection on science learning based on waste management and student creativity development. The strong emergence of the terms learning, students, and education illustrates that the entire document is centered on the educational context, specifically how the learning process is designed to enhance thinking skills and scientific creativity through project and experimental activities. The words waste, composting, and science emphasize the integration of environmental issues, such as waste processing, composting, and ecoenzymes into learning, thereby supporting the strengthening of science literacy as well as sustainability awareness. In addition, the terms creativity, model, project, research, and skills indicate that many of the studies in this corpus use project-based learning models, RBLSTEM, and other innovative approaches to hone 21st-century skills, especially creativity and higher-level thinking skills. Thus, the NVivo word cloud confirms that the SLR study conducted will interact closely with the core themes of waste-based science and STEM learning, creativity, and innovative pedagogical approaches oriented towards environmental sustainability.



Figure 5. *World Cloud*

Figure 7 presents a tree map that, through NVivo analysis, visualizes the hierarchy and proportion of the occurrence of keywords in the corpus of research related to science learning and waste management. The box with the largest size is dominated by the words learning, waste, and science, which shows that the most intensive scientific activities focus on learning design, waste issues (waste/composting), and the context of science as the core of the study. Other words that also occupy a fairly large box such as students, creativity, skills, composting, education, models, projects, and research confirm that the development of creativity, thinking skills, and waste treatment projects are the center of methodological attention in these studies. Meanwhile, smaller boxes containing terms such as https, doi, class, data, results, journal, stem, eco, technology, and the like reflect more specific or peripheral aspects, such as the technical details of the publication, the STEM context, and the data analysis components that support the main topic. This tree map visualization is important because it helps identify core topics (learning, waste, science, students, creativity) as well as supporting themes that form a pattern of scientific concentration in

the realm of waste-based learning and sustainability in science education.

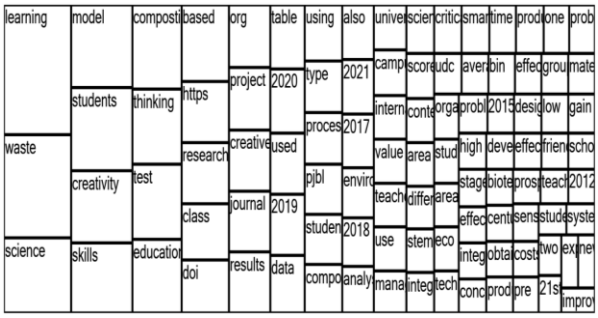


Figure 6. *Tree Map*

The cluster visualization in Figure 7 presents a thematic structure in the study "Study of the Role *of Item Response Theory* in the Development of *Computerized Adaptive Test*", where keywords are grouped based on co-occurrence and conceptual proximity. The dominant blue cluster in the top center represents the core of the *topics of Item Response Theory* (IRT) and *Computerized Adaptive Test* (CAT), encompassing fundamental technical keywords such as "item," "test," "model," "ability," "difficulty," "measurement," "score," "calibration," "parameters," "precision," and "estimation," which form the theoretical and practical foundations of this field. The brown/orange cluster at the bottom left highlights the specific applications and contexts of IRT and CAT, most likely related to aspects such as "education," "learning," "data analysis," "research," "study," "performance," "change," or specific research populations. The green cluster at the top right shows more methodological or evolving topics, such as "computer," "adaptive," "algorithm," "feedback," "system," "design," "efficiency," "validation," or "ethics" and "equity" issues in adaptive testing. Finally, small, scattered yellow/reddish clusters indicate specific issues, *niche vocabulary*, or concepts that are less prominent but relevant in a narrower context, such as specific statistics, analytics software, or unique implementation challenges. Thus, this visualization as a whole helps in understanding the conceptual landscape, key focus areas, as well as potential relationships between concepts in the literature.



Figure 7. *Cluster Analysis*

6. Qualitative Analysis of AI and IRT Integration in CAT Development to Improve the Effectiveness of Assessment in Learning

The following table presents a systematic synthesis of 12 selected articles illustrating the evolution of the role of *Item Response Theory* (IRT) in the *Computerized Adaptive Test* (CAT) ecosystem. Recent literature shows a paradigm shift in CAT development, moving from mere efficiency of reducing question items to the integration of more complex methodologies, such as the incorporation of physiological signals, *machine learning*, and response time estimation. This analysis maps how the IRT model is utilized not only as a statistical tool, but as an adaptive foundation for assessment innovation in the digital age.

Table 1. Summary of Thematic Focus 15 Articles Related to Waste Utilization and Biotechnology Learning

Articles (Author, Year)	Thematic focus related to SLR (organic waste, biotechnology, PjBL/STEM, scientific skills & creativity)
Burch *et al*. (2023)	Using sustainability technology in schools; relevant as the context of Education for Sustainability, it is still not directly on waste biotechnology and has not measured scientific skills in detail.
de Sousa *et al*., (2025)	Utilizing residual biomass in theoretical-practical activities; Supports understanding of chemical–environmental concepts and scientific writing skills, close to simple waste-based biotechnology.
Fentiana *et al*., (2025)	Recycling of paper waste within the framework of RBLSTEM; highlighting increased creativity through projects based on environmental problems, can be used as a model for the context of organic waste.
Del-Río *et al*. (2025)	Podcast project on waste biomass valorization; increase creativity, teamwork, and circular economy awareness, but science process skills are not specifically measured.
Januet *et al*. (2025)	RBLSTEM-based paper waste treatment projects; focusing on strengthening students' creative thinking skills.
Astuti *et al*. (2025)	Utilizing vegetable waste and fruit peels for ecoenzymes in RBLSTEM; is very relevant to organic waste biotechnology and the improvement of scientific literacy.
Calvo & Soto, (2021)	Integration of food waste compost and campus vegetable gardens; provide an institutional-scale composite biotechnology model, but has not measured student learning outcomes.
Longo *et al*. (2021)	5G-based smart waste management system; relevant to waste management infrastructure, but not focused on biotechnology learning or students' scientific skills
Rosdiana *et al*. (2018)	Science–Environment–Technology–Society courses; emphasizing the character and ecopreneurship of students related to environmental issues, without a special focus on waste biotechnology.
Nizaar *et al*. (2017)	Waste treatment project programs with economic value; proven to increase confidence and creativity, relevant for the green entrepreneurship dimension within the framework of PjBL.
Rohman *et al*. (2024)	Project-based EthnoecologicalSTEM model; increase critical thinking, creativity, and mastery of science concepts, becoming a strong reference for the effectiveness of PjBLSTEM.
Atmojo & Sajidan (2020)	CreativityLearning Based Discovery Skill model on biotechnology materials; focus on improving creative thinking skills, but not yet using the context of organic waste.
Sukra *et al*. (2025)	Environmentally friendly projects for prospective teachers; increase scientific creativity, combine PjBL and mixed learning with the context of environmental issues.
Mariyam *et al*. (2017)	Comparing the types of science curriculum integration (shared vs integrated) to creativity; provide insight into the structure of the curriculum, not specifically waste or biotechnology.

Atmojo & Sajidan (2020)	The application of CELBadis to simple food biotechnology; Demonstrating the effectiveness of the discoverybased model on creativity, opening up opportunities combined with organic waste.

This SLR shows that the integration of organic waste and sustainability issues in new science/biotechnology learning is explicitly seen in some key studies, while others make more use of the general environmental context. The use of vegetable waste and fruit peels for ecoenzyme production in the RBLSTEM scheme has proven to be effective in increasing students' scientific literacy and being a direct example of simple biotechnology based on organic waste (Astuti *et al*., 2025). A similar approach is seen in the use of residual biomass in theoretical–practical activities to strengthen chemical–environmental concepts and scientific writing skills (from Sousa *et al*., 2025) and the integration of food waste composting systems and vegetable gardens on campus as institutional composting biotechnology practices (Calvo & Soto, 2021), although the last two studies have not detailed measuring science process skills. These findings form a solid basis for the title "Utilization of Organic Waste in Biotechnology Learning for the Enhancement of Scientific Skills and Creativity".

From a pedagogical perspective, various Project-Based Learning and STEM models consistently enhance creativity and scientific competence in both waste-related and general biotechnology contexts, while also demonstrating potential to shape students' real-world environmental behaviors. RBLSTEM-based recycling of bags and waste paper not only increases students' creativity and creative thinking (Source: *et al*., 2025; Januet *et al*., 2025) but also encourages them to adopt practical waste-reduction habits such as sorting paper waste and reusing materials at home and school. EthnoecologicalSTEM project-based learning further improves critical thinking, creativity, and mastery of science concepts (Rohman *et al*., 2024), with several studies noting that such culturally contextualized activities promote stronger environmental care attitudes. Ecofriendly project-based blended learning strengthens scientific creativity among prospective teachers (Sukra *et al*., 2025) while motivating them to model responsible waste-handling practices during teaching practicum. Similarly, wastepreneurship programs have been shown to raise students' confidence and creativity through hands-on waste treatment, often resulting in increased interest in school-based waste initiatives and community recycling activities (Nizaar *et al*., 2017).

In the biotechnology domain, the CELBadis model effectively enhances creativity in biotechnology topics and simple food biotechnology (Atmojo & Sajidan, 2020; I R W Atmojo *et al.*, 2019), and such inquiry-based tasks frequently lead students to replicate simple fermentation or eco-enzyme activities at home. Other studies broaden the scope through onsite sustainability technologies (Burch *et al.*, 2023) podcast assignments on agroindustrial waste biomass valorization (Del-Río et al., 2025), and character-strengthening programs focusing on ecopreneurship through SETS courses (Rosdiana *et al*., 2018). Shared vs. Integrated models further provide insight on curriculum structures supporting creativity (Mariyam *et al.*, 2017), while the development of 5G-based smart waste

systems on campus (Longo *et al*., 2021) illustrates how technological infrastructure can reinforce sustainable waste behaviors among students and the broader academic community.

Cross-study analysis reveals several methodological and contextual gaps that are important for the formulation of this conceptual framework of SLR. Few studies have simultaneously utilized organic waste as the main material of biotechnology, used explicit PjBL/STEM frameworks, and measured scientific skills with standardized quantitative instruments; Most studies emphasize general creativity, character, or environmental awareness without detailed indicators of the science process (e.g. Nizaar *et al*., 2017; Rosdiana et al., 2018). The level context is also spread between school students, students, and prospective teachers without systematic comparison, while some studies are at the institutional level without a focus on the classroom (Calvo & Soto, 2021; Longo *et al*., 2021). Based on this synthesis, the SLR affirms the need for a framework that integrates the use of organic waste in biotechnology experiments, PjBL/STEM structures (including RBLSTEM, CELBadis, ecofriendly PjBL, and ethnoecologicalSTEM), as well as standardized measurements of creativity, scientific literacy, and ecopreneurial character as the foundation for the development of innovative science curricula relevant to sustainability and 21st-century competence.

CONCLUSION

This SLR synthesis emphasizes that the use of organic waste in biotechnology learning is a pedagogical approach with strong potential to simultaneously address environmental sustainability issues and strengthen students' 21st-century skills. The literature consistently shows that organic-waste contexts such as eco-enzyme production, composting activities, and residual biomass utilization serve as authentic vehicles to connect biotechnology concepts with real-life experiences, foster ecological awareness, and enhance students' scientific literacy and ecoliteracy. Theoretically, the synthesis integrates perspectives from sustainable development, contextual biotechnology, and ethnoscience, forming a comprehensive conceptual understanding of organic waste as a bridge between scientific knowledge, local wisdom, and SDGs-oriented learning.

In terms of methodology and context, this study identifies the dominant trend of using Project-Based Learning and STEM approaches (and their variants), which are reported to be effective in improving creativity, critical thinking, scientific skills, and ecopreneurship when combined with organic-waste-based projects and supported by digital technologies such as e-LKPD, live worksheets, podcasts, and web-based modules. However, gaps remain, particularly the limited number of studies that simultaneously measure scientific skills and creativity using standardized instruments, inconsistencies in experimental design quality, and constraints in generalization across educational levels and cultural contexts. The SLR's main contribution is the development of a conceptual framework that links organic-waste-based biotechnology activities, PjBL/STEM structures, indicators of scientific skills and creativity, local wisdom, and technological support to inform the design of innovative and sustainability-oriented science instruction.

To extend the practical relevance of these findings, this review recommends several actionable steps for policy and educational practice. First, curriculum developers and schools can adopt ready-to-use PjBL modules centered on organic waste, accompanied by clear safety guidelines for handling biological materials and simple protocols for waste processing to ensure responsible implementation. Second, teacher training programs should integrate workshops on contextual biotechnology, eco-enzyme projects, and experiential STEM pedagogy to strengthen teachers' capacity to facilitate sustainability-aligned learning. Third, education authorities and research institutions are encouraged to establish an open-access repository containing standardized learning protocols, assessment instruments, rubrics for scientific creativity, and sample student artifacts. Such a repository would support transparency, facilitate replication, and promote the wider adoption of evidence-based biotechnological learning models. Collectively, these recommendations provide theoretical, methodological, and practical foundations for the development of science curricula that are innovative, sustainable, and responsive to 21st-century competence needs.

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